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Bibliography on Propulsion Airframe Integration Technologies for High-Speed Civil Transport Applications: 1980–1991

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BIBLIOGRAPHY ON PROPULSION AIRFRAME INTEGRATION TECHNOLOGIES FOR HIGH-SPEED CIVIL TRANSPORT APPLICATIONS: 1980-1991

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LIST OF ABBREVIATIONS

The following abbreviations may be used in the bibliographic citations in this document.

AAAF	Association Aeronautique et Astronautique de France
AAS	American Astronautical Society
AFFDL	U.S. Air Force Flight Dynamics Laboratory
AFFTC	U.S. Air Force Flight Test Center
AFWAL	U.S. Air Force Wright Aeronautical Labs
AGARD	Advisory Group for Aeronautical Research and Development
AHS	American Helicopter Society
AIAA	American Institute of Aeronautics and Astronautics
AIChE	American Institute of Chemical Engineers
AIP	American Institute of Physics
AMA	American Medical Association
AMDBS	Avions Marcel Dassault Breguet, S.A./France/
APCA	Air Pollution Control Association
APS	American Physical Society
ARC	NASA Ames Research Center
ASA	Acoustical Society of America
ASMA	Aerospace Medical Association
ASME	American Society of Mechanical Engineers
AST	Advanced Supersonic Technology program
ATA	Air Transport Association
ATAA	Air Transportation Association of America
ATF	Advanced Tactical Fighter
ATSF	Avion de Transport Supersonique Futur
CASI	Canadian Aeronautics and Space Institute
CFD	Computational Fluid Dynamics
DARPA	U.S. Defense Advanced Research Projects Agency
dB	Decibel
DGLR	Deutsche Geselischaft fur Luft- und Raumfahrt/Germany/
DLR	Deutsche Forschungsanstalt fur Luft- und Raumfahrt/Germany/
DND	Department of National Defence/Canada/
DOD	U.S. Department of Defence
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
ECS	Environmental Control System
EEC	European Economic Community
EPA	U.S. Environmental Protection Agency
ESA	European Space Agency
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	U.S. Federal Aviation Administration
FAR	Federal Aviation Regulations

FNS	Full Navier-Stokes
GE	General Electric Company
HSCT	High-Speed Civil Transport
HSR	High-Speed Research program
IATA	International Air Transport Association
ICAS	International Council of the Astronautical Sciences
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronics Engineers
JPL	Jet Propulsion Laboratory
JSME	Japan Society of Mechanical Engineers
LaRC	NASA Langley Research Center
LeRC	NASA Lewis Research Center
LFC	Laminar Flow Control
MBB	Messerschmitt-Bolkow-Blohm GmbH/Germany/
NACA	Naturally Aspirated Co-Annular nozzle
NASA	National Aeronautics and Space Administration
NASP	National Aerospace Plane
NATO	North Atlantic Treaty Organization
NCAR	National Center for Atmospheric Research
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPR	Nozzle Pressure Ratio
NSF	National Science Foundation
OAST	Office of Aeronautics and Space Technology/NASA/
ONERA	Office National d'Etudes et de Recherches Aerospatiales/France/
P&W	Pratt and Whitney Company
PAI	Propulsion/Airframe Integration
PNS	Parabolized Navier-Stokes
RAF	Royal Air Force
SAE	Society of Automotive Engineers
SCAR	Supersonic Cruise Aircraft Research program
SCR	Supersonic Cruise Research program
SEP	Societe Europeenne de Propulsion
SERN	Single Expansion Ramp Nozzle
SNECMA	Societe Nationale d'Etude et de Construction de Moteurs d'Aviation
SPL	Sound Pressure Level
SST	Supersonic Transport
STFF	Supersonic Throughflow Fan engine
TAS	Thermal Acoustic Shield
TBE	Turbine Bypass Engine
USAF	U.S. Air Force
VCE	Variable-Cycle Engine
VSCE	Variable Stream Control Engine
WRDC	Wright Research and Development Center/USAF/

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank Chris Domack, of the Lockheed Engineering Sciences Company at NASA Langley, for conducting a literature search on inlet dynamics and unstarts, and for providing extensive editorial recommendations. The authors would also like extend their appreciation to Tony Midea and John Wolter, of NASA Lewis, who made informal reviews and provided additional editorial comments of the bibliography at our request. And finally, a special thanks to Joe Wasserbauer (NASA Lewis) who provided the authors with a list of references from the Inlet Stability Workshop, and for accepting the authors request to serve as the official reviewer for this report.

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SUMMARY

NASA has initiated the High Speed Research (HSR) program, with the goal to develop technologies for a new generation, economically viable, environmentally acceptable supersonic transport (SST), called the High Speed Civil Transport (HSCT). A significant part of this effort is expected to be in multidisciplinary systems integration, such as in propulsion-airframe integration (PAI). In order to assimilate the knowledge database on PAI for SST type aircraft, a bibliography on this subject has been compiled, with over 1200 entries, full abstracts, and indexes. Related topics are also covered, such as: engine inlets, engine cycles, nozzles, existing supersonic cruise aircraft, noise issues, computational fluid dynamics, aerodynamics, and external interference. All identified documents from 1980 through early 1991 are included; this covers the latter part of the NASA Supersonic Cruise Research (SCR) program, and the beginnings of the HSR program. In addition, some pre-1980 documents of significant merit or reference value are also included. The references were retrieved via a computerized literature search using the NASA RECON database system.

I. DISCUSSION OF BIBLIOGRAPHY

1.0 INTRODUCTION

This bibliography covers technologies and components related to propulsion-airframe integration (PAI) for supersonic transport (SST) type aircraft, such as the High Speed Civil Transport (HSCT). Most documents cited were published between 1980 and early 1991. Extensive bibliographies from previous SST programs fully cover the period prior to 1983, and these have been identified in the reference section. Therefore, the goal of this compilation is to provide a complete coverage of the subject since 1980, especially with regard to aerodynamic interference, systems studies, and propulsion system components. Secondary topics related to PAI are also included, but are not covered comprehensively.

A detailed literature search was conducted using the NASA/RECON informational retrieval system for technical publications. The strategy used to conduct the literature search, and additional information on the NASA/RECON database itself, are described in more detail in Appendix A. The citations were downloaded from NASA/RECON to a microcomputer for processing. The downloaded citation sets were then reviewed and appropriate references selected. The raw NASA/RECON citations, Figure 1, were modified to fit the format chosen for this bibliography, Figure 2. Information such as the corporate source, STAR numbers, contract or grant number, availability source, report ordering codes, and major and minor subject terms were deleted. The references were then grouped by subject and sorted by date within each subject.

An exact reverse chronological listing by publication date for each category was not practical. The references are generally presented in reverse chronological order by the year of inclusion into the NASA/RECON

Arrangement and Format of Citations

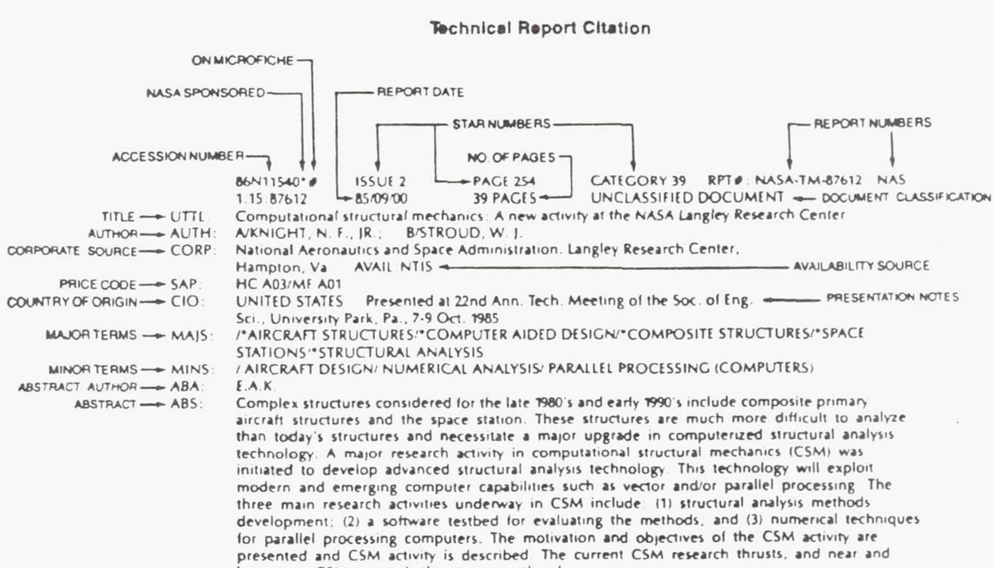


Figure 1. Arrangement and format of NASA/RECON citations.

database. The first two digits of the accession number are the year of inclusion. A further attempt was made to reverse chronologically order the citations by publication year under each accession number year.

Some references have recent accession numbers but much earlier publication dates. There seems to be three common reasons for this: first, the document was published late one year and included in the database the following year; second, an older document was declassified and then included in an unclassified database; and third, the document had been missed by the database when originally published.

For most entries, the accession number is on the last line of the document citation, and above the abstract, see Figure 2. The accession number uniquely identifies each reference, and is the number by which the document may be ordered from the NASA Center for AeroSpace Information (formerly the NASA Scientific and Technical Information Facility). A more complete description of the accession number sequencing and document ordering proceedures can be found in Appendix A.

The initial NASA/RECON literature search strategy was carefully designed to be comprehensive enough in scope to capture all relevant references without including too many irrelevant ones. In practice, the references' "subject terms" which are used in the search, were found to be inconsistent, and vary from one citation to another. It was therefore necessary to make the search wider in order not to miss relevant citations. As stated above, only unwanted citations were removed manually.

Because computer based search procedures are only as good as their key words, and since documents may sometimes miss being included in any one of the NASA/RECON databases, some references were added manually. Manual additions were based on references which the

AUTHORS

REFERENCE NUMBER → **123.** KNIGHT, N. F., JR.; STROUD, W. J.: **Computational structural mechanics: A new activity at the NASA Langley Research Center.** NASA-TM-87612 NAS1.15:87612 1985. ← TITLE ← REPORT DATE

ACCESSION NUMBER → 86N11540

REPORT NUMBERS

ABSTRACT → Complex structures considered for the late 1980's and early 1990's include composite primary aircraft structures and the space station. These structures are much more difficult to analyze than today's structures and necessitate a major upgrade in computerized structural analysis technology. A major research activity in computational structural mechanics (CSM) was initiated to develop advanced structural analysis technology. This technology will exploit modern and emerging computer capabilities such as vector and/or parallel processing. The three main research activities underway in CSM include: (1) structural analysis methods development; (2) a software testbed for evaluating the methods; and (3) numerical techniques for parallel processing computers. The motivation and objectives of the CSM activity are presented and CSM activity is described. The current CSM research thrusts, and near and long term CSM research thrusts are outlined.

Figure 2. Typical HSCT PAI bibliography citation and abstract.

authors had come across during their PAI research activities, and by soliciting other NASA researchers, with PAI experience, for key PAI documents.

The bibliography has also been augmented with references published prior to 1980 which the authors feel have lasting reference value or contain significant technical information pertaining to the understanding of propulsion airframe integration for supersonic transport application. These additional references were added in order that this document may be used as a stand-alone bibliography for HSCT PAI research and development activities.

The bibliography contains unclassified publications only. The need to address classified publications was not deemed necessary for a civil transport program, and a classified search was not attempted. Limited distribution documents with access levels of 'domestic NASA' and below have been included though, and are available only to NASA, other government agencies, or to their contractors. All limited distribution documents **have been identified** with the appropriate distribution caveat in the citation heading. The titles and abstracts themselves, as shown in this document, are not limited distribution; the caveat applies only to the document itself.

The bibliography has been organized into several propulsion system component categories as well as several PAI subject related categories. Many reports contain information which fit more than one category in the bibliography. An attempt was made to list a reference in every category to which it applied, rather than trying to make an arbitrary determination as to which category it best belongs. This results in many references being cited multiple times throughout the bibliography. There are a total of 1209 citations listed in this bibliography, which represent at least 750 individual references. It was desired to make each category complete and independent. The intent was to avoid requiring the reader to search through their primary category of interest, and then have to search through other related categories to find all pertinent references.

There are many instances where an author has released a similar document on the same piece of work but under a different publication. The accession number for each publication will therefore be different. Both references will be cited in this bibliography, even though they may have the same or similar abstracts, because the content of each document may differ.

Abstracts have been included for each citation, if one is available, in order to provide a useful summary of the document. For those citations without abstracts, but with major and minor topics, a narrative of the topics has been included as the citation's abstract. The major topics have been listed first. Some citations have no abstract or topic narrative because one was not included in the RECON citation. The authors reserve the right to make slight modifications to the provided abstracts if conditions warrant the changes. The most common modification was when an abstract was not complete due to a problem during the downloading procedure.

To provide background to the bibliography, a narrative section has been included. A brief discussion of past supersonic research will provide an introduction to NASA's High-Speed Research (HSR) Program. A discussion of the HSR program, and the High-Speed Civil Transport (HSCT) effort will be presented, and will review the economic, environmental, and technical challenges of fielding a second generation supersonic transport (SST). A short section on propulsion/airframe integration (PAI) will follow, and discuss some of the technical issues of PAI and NASA's PAI efforts.

2.0 BRIEF HISTORY OF SUPERSONIC CRUISE FLIGHT

The door to supersonic flight was first opened in October 14th, 1947 by a Bell X-1 (Figure 3) rocket powered research aircraft, piloted by USAF Captain Charles Yeager. This event opened a whole new area of the flight envelope beyond the sound "barrier", previously thought to be impenetrable. Many other supersonic aircraft have followed the X-1, both research and production, such as the X-2, F-100, B-58, F-106 (Figure 4) and many others. But these were all supersonic "dash" aircraft, capable of faster than sound flight only for short periods of time, using afterburners or rockets, and at great expense to the range.

A supersonic cruise aircraft, on the other hand, is one that is intended to fly most of its design mission faster than the speed of sound. Many civil and military supersonic research and production aircraft, especially the Convair B-58 "Hustler" bomber (Figure 5), have provided much valuable experience in supersonic flight. The first real supersonic cruiser, was the North American XB-70 "Valkyrie" (Figure 6), designed for Mach 3 cruise, with intercontinental range and a 22,727 Kg (50,000 lb) payload. It was essentially canceled by the Eisenhower administration, and never progressed beyond the prototype and flight test stages. The Lockheed SR-71 "Blackbird" reconnaissance aircraft (Figure 7a), and its predecessor the YF-12 interceptor (Figure 7b), are also capable of Mach 3 supersonic cruise, but they are essentially flying fuel tanks with no appreciable payload. More recently, the YF-22 and YF-23, Advanced Tactical Fighter (ATF) full-scale development prototypes, have achieved non-afterburning supersonic cruise, primarily due to advances in jet engine technology.

On June 5, 1963, the US Supersonic Transport (SST) program was initiated by President John F. Kennedy, with the Federal Aviation Agency (FAA) to manage the program. Even before that day, both the Anglo-French consortium, and

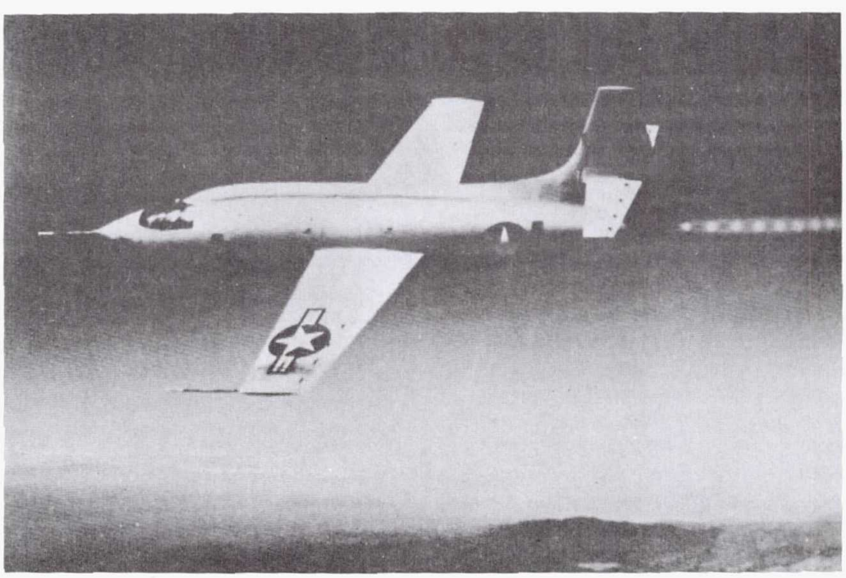


Figure 3.The first supersonic airplane - the U.S. Air Force/Bell X-1.

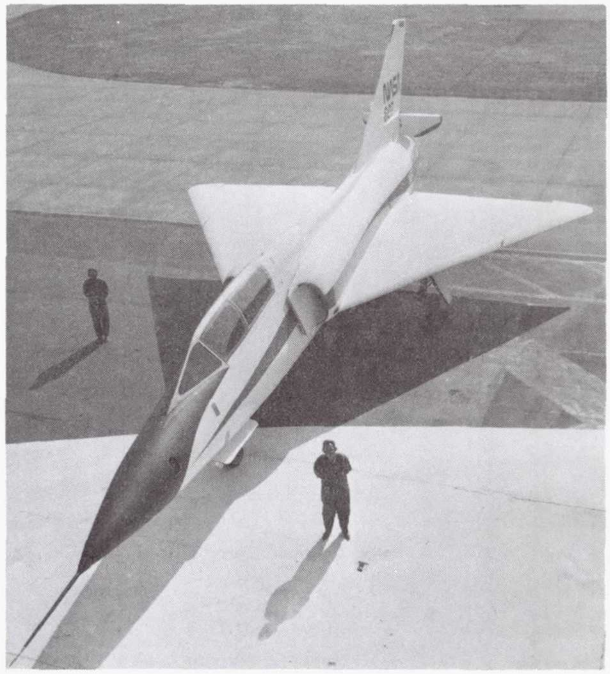


Figure 4. The F-106 was a supersonic interceptor which had a maximum speed of 2,455 km/hr (1,525 mph).

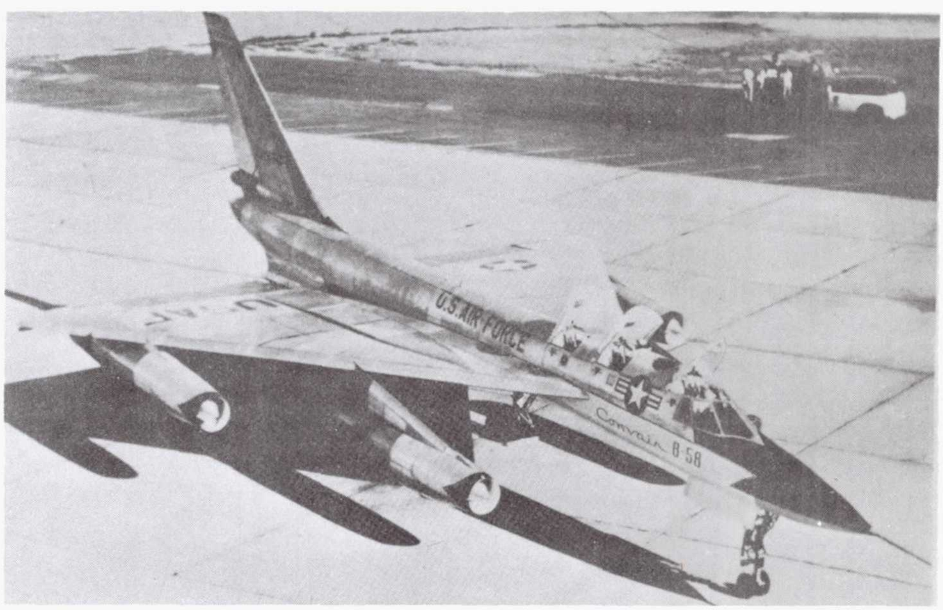


Figure 5. The B-58 was the first supersonic bomber ever to go into production, and could reach a maximum speed of 2,230 km/hr (1,385 mph).

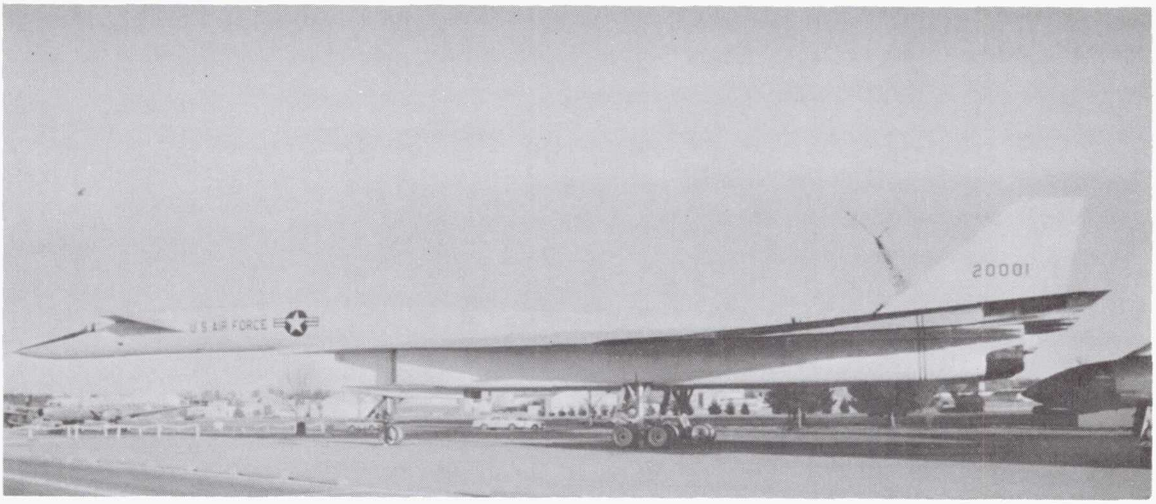


Figure 6. The XB-70 was the first true supersonic cruise aircraft. It was built by North American for the U.S. Air Force.

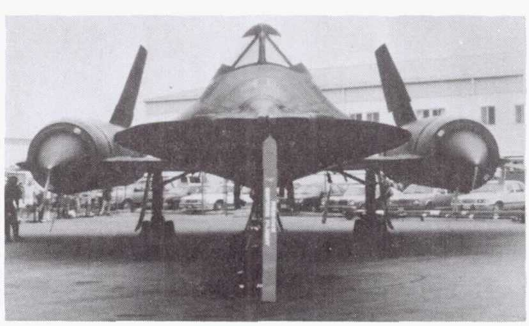


Figure 7a. The Lockheed built SR-71 is a Mach 3, high flying reconnaissance aircraft for the U.S. Air Force.
Figure 7b. This YF-12 was used for NASA supersonic cruise research.

the Soviet Union had begun work on their Concorde (Figure 8) and Tupolev Tu-144 (Figure 9) supersonic transports, respectively. Back in the United States, the winner of the SST design competition was to be the Boeing-General Electric B-2707-200 (Figure 10), with four engines and a variable geometry swing-wing. The wing was later changed to a double-delta planform (B-2707-300, Figure 11) for weight considerations. The concept was intended to leapfrog its competitors, by flying faster (Mach 2.7) with larger payloads, but these introduced new technical problems. In addition, there were significant delays at the FAA in selecting the final configuration. Even with strong support from the administration, and support in the House, the Senate voted to cancel the SST, and the House was not able to rescue the program. Finally, the entire program was canceled in 1971, citing issues of engine noise, sonic boom, ozone depletion, economics, and technical risk.

Meanwhile, as the US SST sank in a political quagmire, the Concorde program continued on. First flight was on March 2, 1969 and commercial service began in 1976. But many problems became apparent: the engine noise at takeoff exceeded most airport regulations resulting in severe limits being imposed on operations; the fuel consumption was very high, substantially raising operating costs as fuel prices rose sharply in the 1970's; questions about ozone depletion remained unanswered; supersonic flight over land was disallowed because of sonic boom; and the range was way too short to serve the major Far East markets. In the end, only 16 Concordes were built, and only two airlines (British Airways and Air France) made purchases. The Concorde continues to fly transoceanic routes around the world, at very high fare premiums.

Also in the supersonic sweepstakes was the Tupolev Tu-144, and in fact, it was the first one to fly, but the program was so rushed that many flaws were designed into the aircraft. Its story was riddled with disasters: On December 31, 1968, one month before the Concorde, a very much prototyped Tu-144 first took to the air in what is said to have been a mad, desperate rush to beat the Concorde; at the 1973 Paris Airshow, a prototype broke up in midair before an international audience; in the first two years of commercial service starting in 1975, it flew only cargo, because nobody would trust it on scheduled passenger service; less than a year after passenger service started, a major crash in 1978 forced it out of passenger service; freight duties continued for a few years, before it was most likely mothballed in the mid 1980's.

In the wake of the US SST program's demise, questions remained about future air transportation, and the possibility of future supersonic transports, especially if it were to be constructed by foreign countries. Therefore in fiscal year (FY) 1973, the administration directed NASA to initiate the Advanced Supersonic Technology (AST) program, later called the Supersonic Cruise Aircraft Research (SCAR), and then Supersonic Cruise Research (SCR). In FY76, a related program called Variable Cycle Engine (VCE) technology program was started at NASA Lewis Research Center. The VCE program was eventually canceled in 1981 due to funding limitations.

The SCR program was a focused Research and Technology (R&T) effort, with the objectives: to provide a technology base for future civil and military supersonic aircraft; to provide data to assess environmental and economic impacts of SSTs; and to determine the benefits and tradeoff of advanced technologies. The main areas studied were: system studies, propulsion, propulsion-airframe integration, stratospheric emission impact (ozone depletion due to nitrogen oxides (NOx)), structures and materials, aerodynamic performance, and stability/control.

Significant progress was made in SCR, but challenges remain to an economically viable, environmentally acceptable SST. Jet engine noise reduction studies included coannular

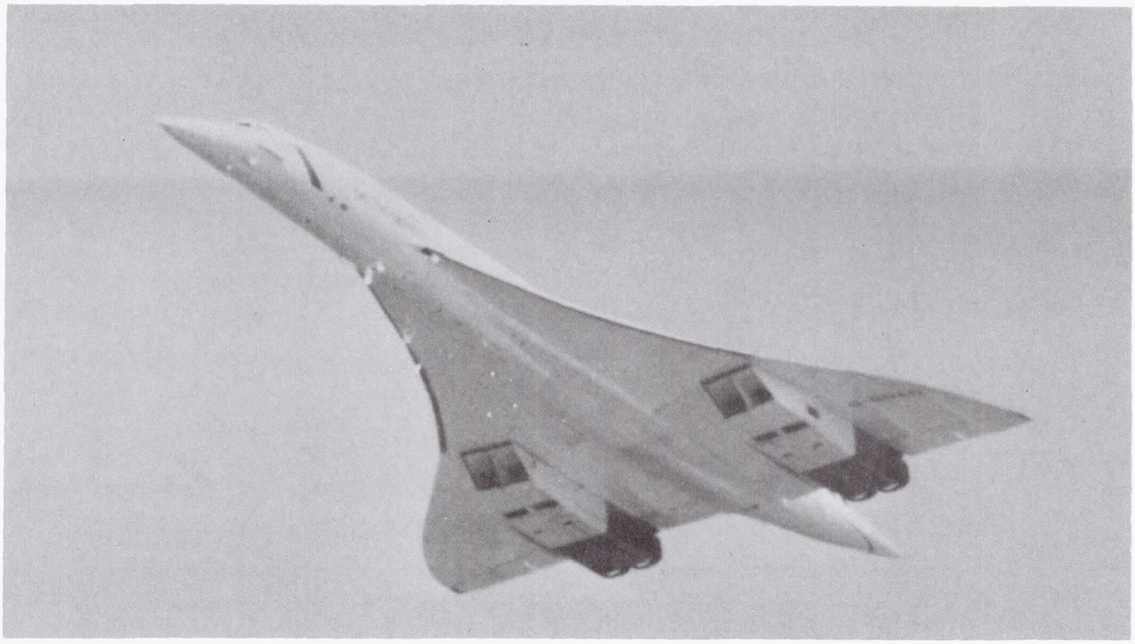


Figure 8. Today the Concorde is the world's only passenger carrying supersonic transport. A technical wonder when it first flew, but it now lacks the ability to meet today's new economic and environmental requirements.

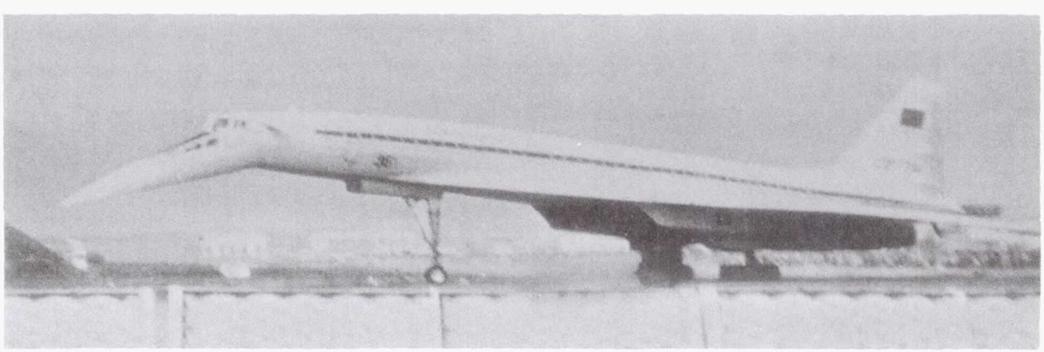


Figure 9. The Tu-144 was the first supersonic transport to fly, but technical problems soon grounded it.

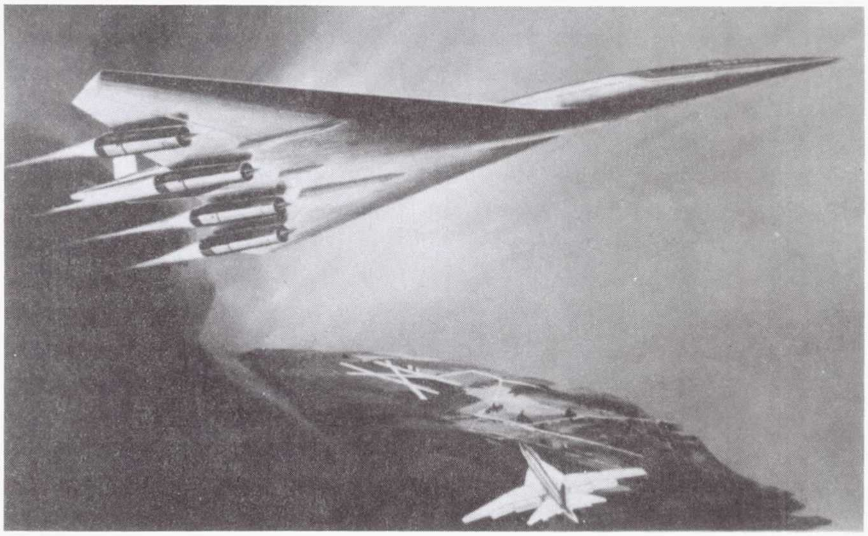


Figure 10. The Boeing/General Electric 2707-200 won the U.S. SST competition. Technical, environmental, and program cost considerations kept it from being built.

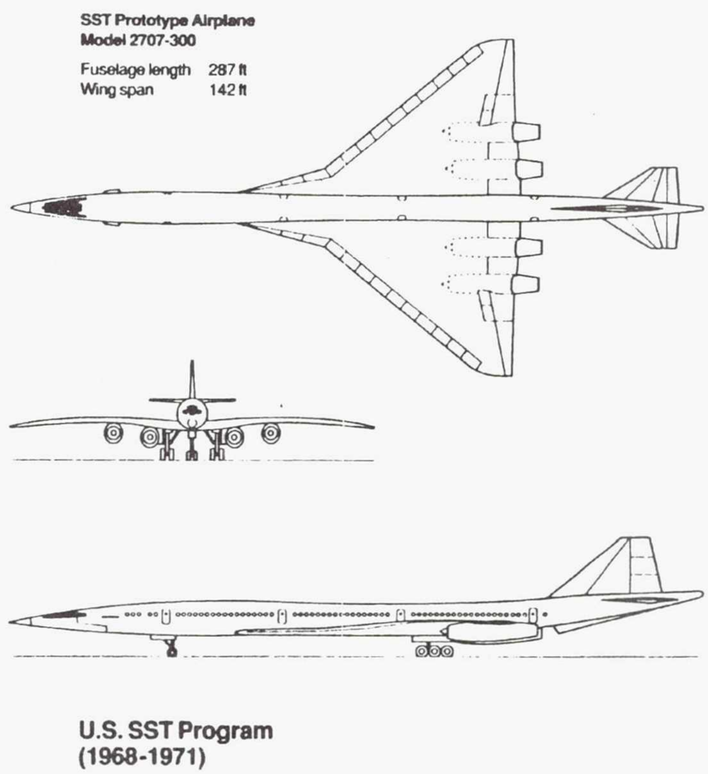


Figure 11. Schematic of the Boeing/General Electric 2707-300 with the fixed delta wing.

streams, thermal acoustic shielding, mechanical suppressors, inverted velocity profiles, acoustically treated ejectors. Low emission staged duct burners were studied. The arrow wing configuration was extensively studied. However, reducing noise and emissions without seriously penalizing performance is still difficult.

Good documentation is one strong point of the SCR program. Two SCAR/SCR conferences were held, and the proceeding were published as conference publications NASA CP-001 (ref.s 48-49) and NASA CP-2108 (ref.s 38-39). Three complete bibliographies list the over 1000 documents produced: NASA RP-1003 (ref 137), NASA RP-1063 (ref 130) and NASA TM 81814 (ref 132). Finally, an excellent and complete summary of the entire program is given in NASA SP-472 (ref 21) Supersonic Cruise Technology.

Figure 12 shows the history of NACA/NASA supersonic cruise research efforts, with several milestone events shown for reference. The figure also shows the present NASA supersonic cruise transport effort: the High-Speed Research (HSR) Program, which includes the High-Speed Civil Transport program.

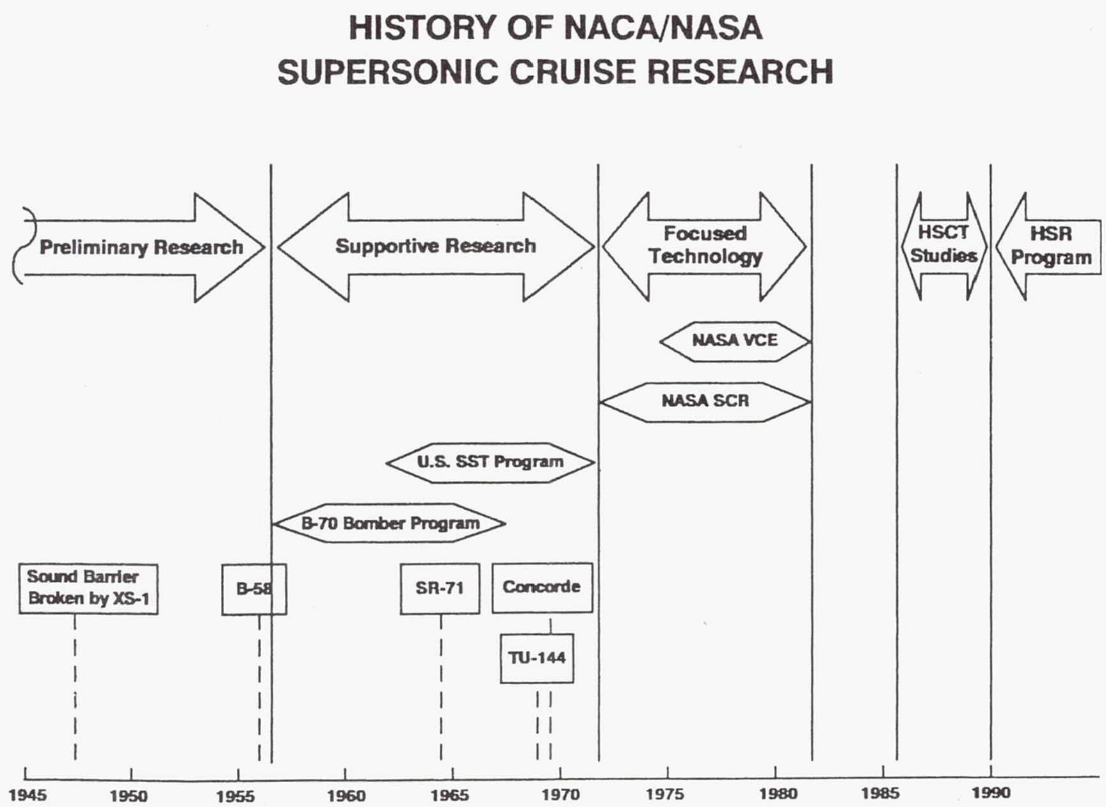


Figure 12. History of NACA/NASA supersonic cruise research.

3.0 THE HIGH SPEED RESEARCH (HSR) PROGRAM

In 1985 and 1987, The White House Office of Science and Technology (OSTP) issued reports on National Aeronautical R&D Goals. Three areas were addressed: subsonics, supersonics and transatmospherics. The supersonic goal is to develop a long range, supersonic transport for commercial as well as military applications. In addition, SCR research and Concorde operational experience had provided confidence that a successful second generation supersonic transport (SST) could be developed. As a result, the NASA High Speed Research (HSR) program was initiated, to research and develop technologies for this new SST, now called the High Speed Civil Transport (HSCT), (see Figures 13 and 14). This project is anticipated to be the cornerstone of NASA aeronautics in the 1990's.

In order to be successful, 'economically viable' and 'environmentally acceptable' are two key qualities that the new HSCT aircraft must be able to satisfy. Figure 15 shows the four major technical challenges to the HSCT: economics, emissions, high temperature materials, and noise. A number of HSCT system studies conducted by NASA and industry since 1987 have shown that there will be a substantial market for this class of aircraft in the post 2000 timeframe, provided those conditions were met. The FAR 36 stage III airport noise regulations must be met, to assure that operating restrictions will not be imposed (curfews, etc.). There must be no appreciable sonic boom over land; this can be accomplished by flying subsonically over land, or by using a low-boom design. The ozone depletion due to nitrogen oxides (NOx) emissions must be minimal; therefore, the new engine combustors must be of a low-NOx emission design. Fares must be no more than a full-fare subsonic coach, where fuel consumption is a key driver of cost. The range must be long enough to serve growing far-East

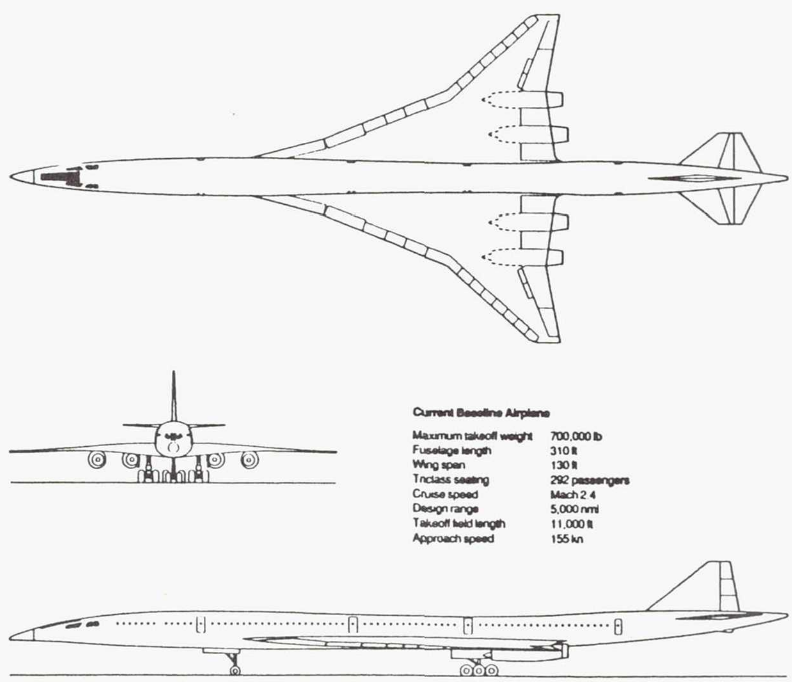


Figure 13. The Boeing baseline High-Speed Civil Transport (HSCT) concept.

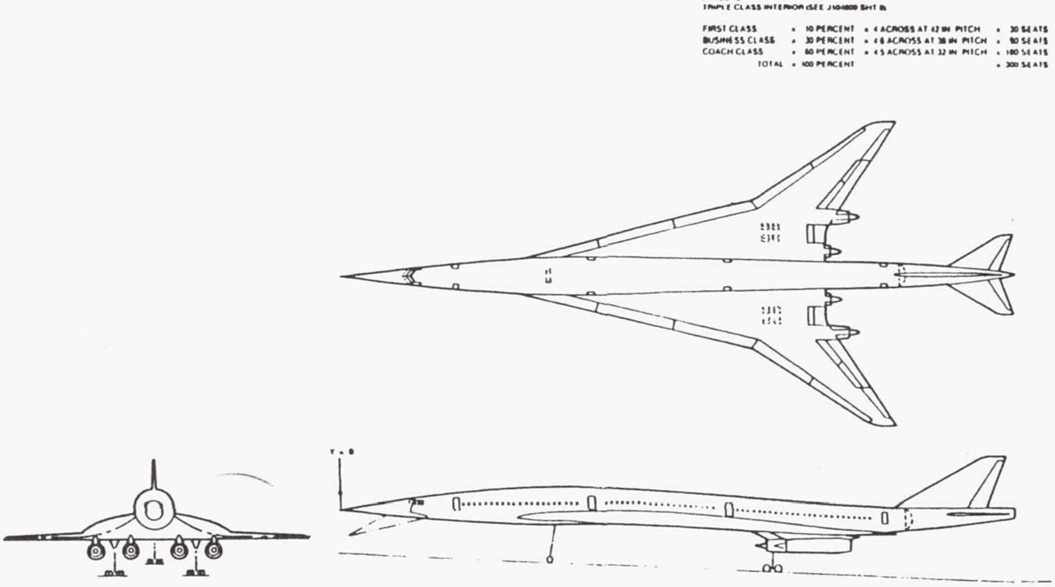


Figure 14. An early Douglas baseline Mach 3.2 HSCT concept.

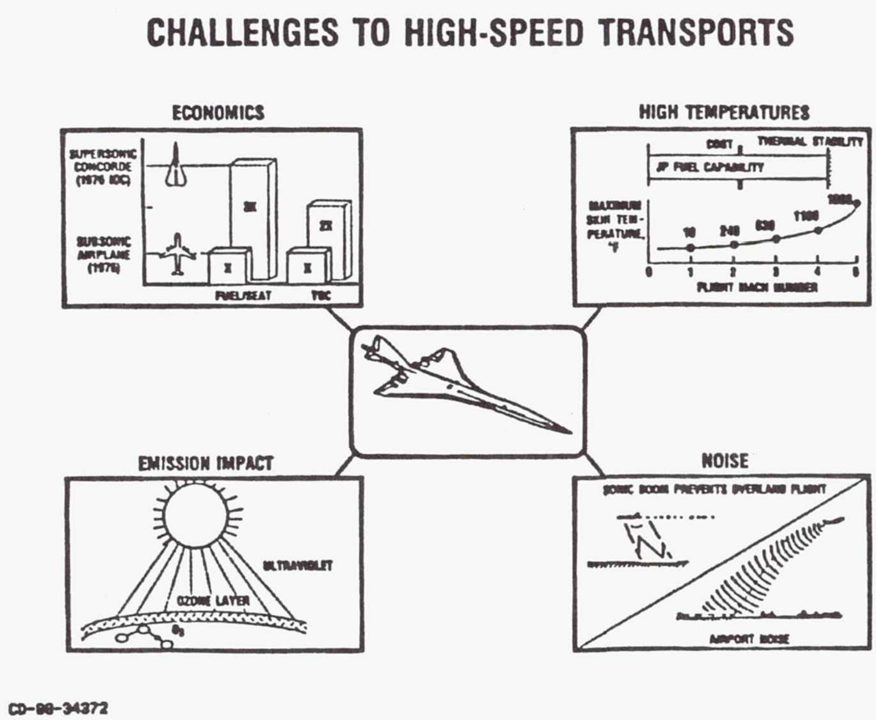


Figure 15. Challenges to High-speed transports.

markets, such as with a Los Angeles - Tokyo route. Lastly, the standards of safety and comfort should meet those of existing transports; inlet unstarts must be reasonably mild, and space radiation exposure levels at these higher altitudes must be within acceptable levels.

3.1 Projections of Future Air Travel

Since the introduction of reliable commercial jet transports, in the late 50's and early 60's, long range travel has gotten easier, and most notably, quicker. Over the last twenty years worldwide air travel has tripled to a current level of around 1000 billion revenue-passenger-miles per year (Figure 16). The next twenty years should see this value grow by 2 1/2 times. And through the rest of this century, the worldwide large transport market is estimated to average about $20 billion dollars a year. By 1992, sales of commercial air transports, engines and related parts are predicted to grow to around $47.4 billion, see Figure 17. After 1991, U.S. commercial aircraft sales should exceed sales of U.S. military aircraft, see Figure 18.

NASA and industry studies of the long-haul transport market (the market for which the HSCT will compete) is projected to double by the year 2000. This assessment indicates a strong market demand for an economically viable, and environmentally compatible HSCT. The NASA High-Speed Research Program (HSR) and industry expects the majority of this growth to be in long-range international travel, specifically, that to the Asian/Pacific Rim region from Europe and North America. Growth and high volume traffic is also expected in the other international long-haul markets like, North America to Europe. According to Boeing studies, a competitive HSCT aircraft could capture up to 75 percent of the long-haul, international market, which would result in an HSCT fleet of 900 to 1200 aircraft valued at over $250 billion by the year 2015. The opening of the Eastern Block nations should also increase long-range international travel demands.

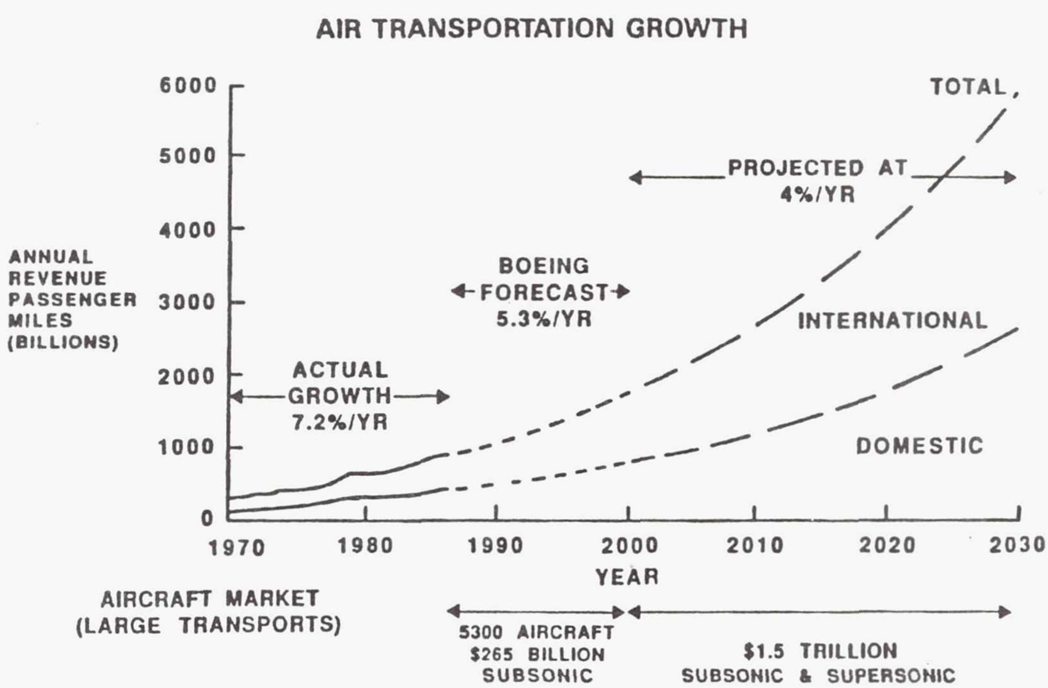
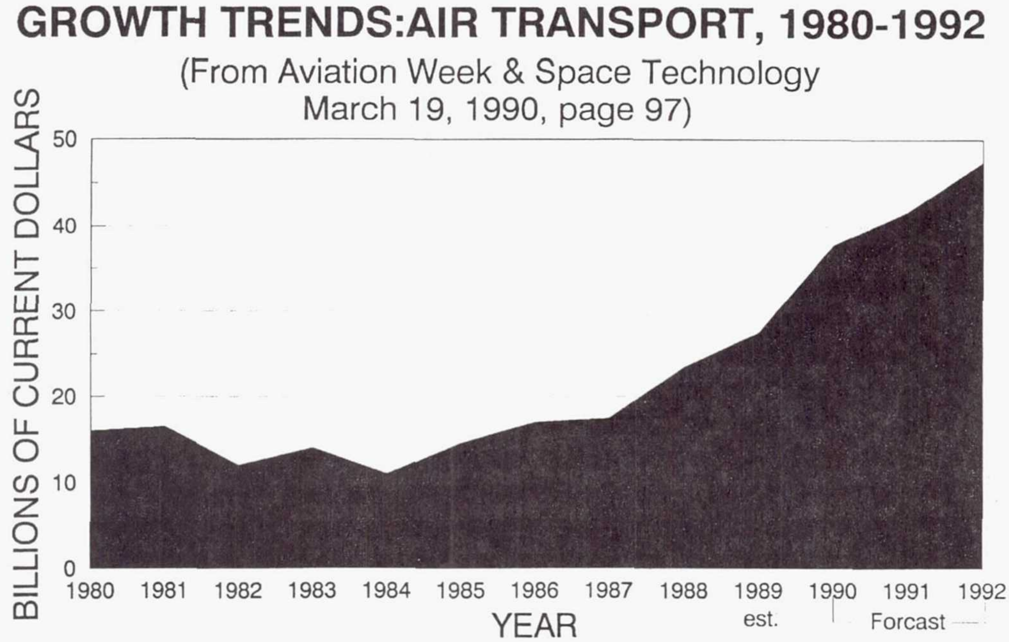


Figure 16. Air transportation growth.



Comercial transport includes aircraft, engines, and parts and accessories. Included are civilian helicopters. As given in the Commercial transport sales refers to dollar sales of U.S.-manufactured fixed-wing aircraft over 33,000 lb., including imports.

Figure 17. Growth trends: Air transport, 1980-1992. (Adapted from chart of same title: Aviation Week & Space Technology/March 19, 1990, 97)

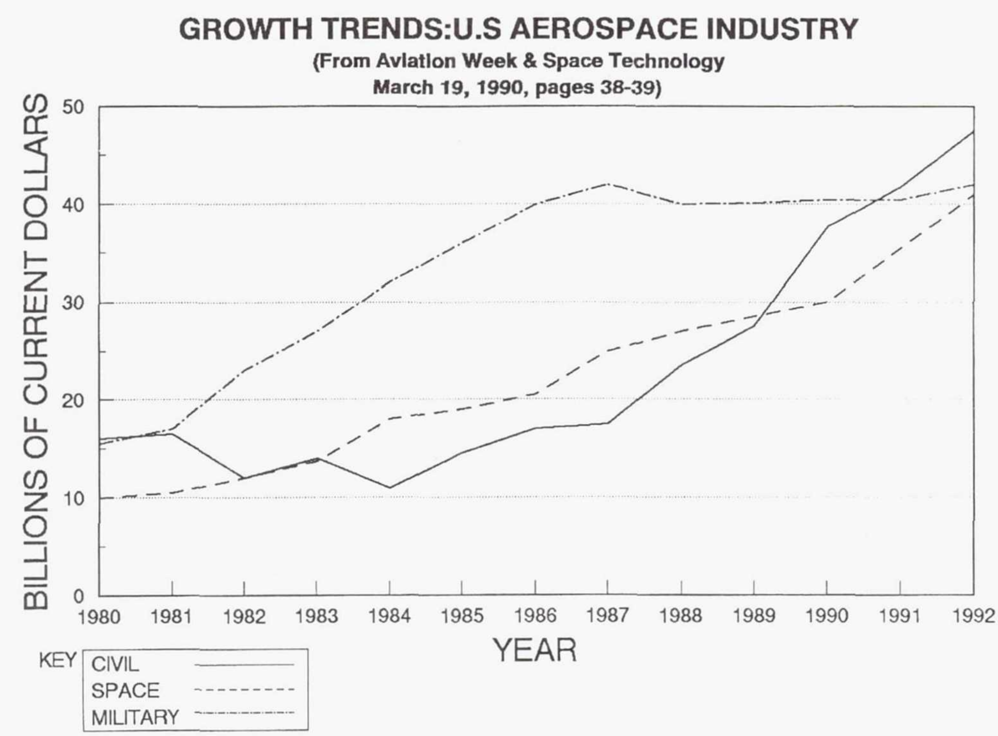


Figure 18. Growth trends: U.S. aerospace industry. (Adapted from chart of same title: Aviation Week & Space Technology/March 19, 1990, 39-39)

3.2 The Need for Another SST Program

NASA and the U.S. aircraft manufacturers are not alone in their assessment of long range transport growth. British Aerospace Commercial Aircraft and Aerospatiale, of France, are conducting a five year $34 million study into determining the technical and economic feasibility of a successor to the supersonic Concorde aircraft. This joint study will continue the work British Aerospace and Aerospatiale have already conducted under their Advanced Supersonic Transport (AST) and Avion de Transport Supersonique Futur (ATSF) programs, respectively. Aerospatiale has around 120 people on its Concorde II program and hopes to be able to field the Concorde II around 2005, when it expects the life expectancy of the original Concorde to expire. Work on a supersonic commercial aircraft is also being pursued separately in both Germany and Japan.

Aviation Week & Space Technology has reported that "Prospects for a next generation supersonic transport were boosted...when five of the West's largest airframe builders agreed to conduct joint feasibility studies. An international airframe manufacturers group was formed in May of 1990 to study the potential for a next-generation commercial supersonic transport aircraft. The group originally started with five airframe manufacturers from the United States, the United Kingdom, France, and Germany. The group was later expanded to include Alenia Aeronautica from Italy and the Society of Japanese Aerospace Companies. Recently, Tupolev of the Soviet Union, has asked to join this international study group. The five original airframe manufacturers were: Aerospatiale, British Aerospace, Boeing, McDonnell Douglas, and Deutsche Airbus. And, the study is scheduled to last for two years.

The international group is looking into technical, environmental, and economic issues specific to a second generation supersonic transport. As part of the group's effort, they will examine the practicality of cooperating on a single, multinational high-speed transport. Several members of the group have expressed a belief that no one nation or company can carry through this project alone. One key point is whether a group of competing companies can work together to produce a follow-on to Concorde.

The formation of this international study group reveals the high risk nature of this program. Aerospatiale has estimated development costs for this next generation SST will be around $10 billion, and Battelle, of Columbus, Ohio, has estimated the development costs to be in the neighborhood of $15 billion.

The Japanese aerospace industry is already engaged in research and development activities in supersonic and hypersonic propulsion and materials. Along with its FSX fighter aircraft program, the Japanese are demonstrating they have a very mature knowledge of supersonic aerodynamics, and aircraft manufacturing. The Japanese have initiated program funding of $120 million for materials development; $165 million for propulsion research; $145 million for definition of test facilities; and an estimated $5 billion for a facilities construction budget. They have also stated a goal to achieve technical leadership in any international HSCT consortium.

The Russians must also be figured into the next SST, since they have built the only other supersonic commercial aircraft, the Tu-144. Additionally, Sukhoi, of the Soviet Union, has already started working with Gulfstream, in the U.S., to design and build a supersonic business jet (Figure 19).

British Aerospace and Aerospatiale have raised the possibility of other international partners joining them in there Concorde II project. The Japanese have also said they would like to participate as partner in the next SST (their long-term goal though, is an even higher speed SST

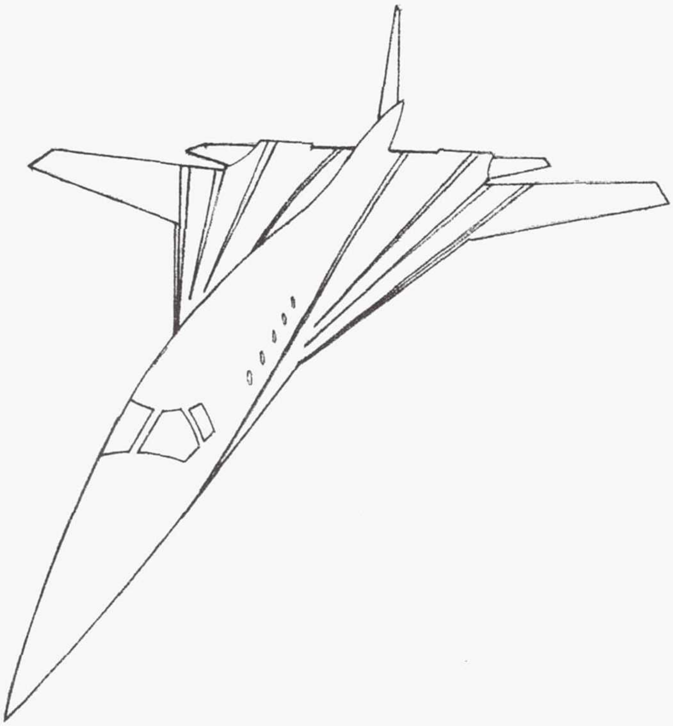


Figure 19. The Sukhoi/Gulfstream supersonic business jet is sized to carry 8 to 12 passengers.

with service entry date 10-15 years later than the next SST). Both Boeing Commercial Airplanes, Seattle, and Douglas Aircraft Co., Long Beach, Calif., have conducted studies which concluded there should be a market for a new SST, flying at two to three times the speed of sound (2187-3240 km/hr, 1350-2000 mph), between the years 2000 and 2015.

Donald A. Graf, McDonnell Douglas program manager for their HSCT program, said "The project is probably bigger than one company," and that "It is in the scope of an international project, but this is something we have to determine. It is not a given." No company is ready to commit to a multi-billion dollar program just yet. They all see that sharing some of the up-front costs to conduct these studies will help to reduce their financial burden if the program doesn't pan out. There are no binding commitments coming out of this study project. The studies purpose, in this respect, is to weigh the advantages of international cooperation versus the risks of the program as a whole. The high costs and the challenging technical requirements associated with an HSCT type aircraft may force the U.S. and international aerospace industries into teaming arrangements.

There are some legal issues which will need to be addressed if it goes beyond the study. The way current laws are written, U.S. manufacturers who would participate in the international development of the "one HSCT" might run the risk of antitrust violations, according to a U.S. government official. The official also said that "These laws were developed because of robber barons and they may not apply to the international market. As competition becomes more international than domestic, the U.S. laws in some cases may not apply anymore." This is one legal question which will need a clarification in order for U.S. to work openly in the international marketplace. Revisions to U.S. antitrust laws are being considered by the appropriate federal agencies, according to the official.

Studies reveal there may only be enough of a market for one new SST aircraft. A key question airframers and propulsion companies will need to answer is how many next generation SSTs the market will be able to bear, Figure 21. Production rates for the next SST were based on estimates that this aircraft will replace a majority of long-range subsonic transports when they come to the end of their operational life. The rate of production was also based on the growth in long-range travel, identified above. The number of aircraft needed would also benefit from the speed factor inherent in this aircraft. Edmund S. Greenslet, president of ESG Aviation Services, said that "Speed has always expanded markets." In today's society, people naturally want to get places quicker. Greenslet also said that a second SST design becomes more of a reality if they would be able

to fly supersonically over land.

The first successful "next generation SST" will probably dominate the long-range market, and may determine the future of the aerospace industry to come. Nihart and Brown, of Boeing Commercial Airplanes, have stated "The development of a U.S. HSCT will continue the recent positive influence of the U.S. aerospace industry on our national balance of trade." and that "A successful U.S. HSCT would ensure American aerospace technical superiority well into the next century."

Economically, this country can not afford to lose the lion's share of the HSCT to foreign competition. This puts great economic pressure on the U.S. aerospace industry, the U.S. government, and the population in general. This economic pressure may influence governmental legislators to pass new laws, and some of the new legislation may not be welcomed by some portions of the population. The reality though is that foreign industry is ready to step in if the U.S. doesn't capitalize on its existing advanced technology and manufacturing capability. The U.S. government, industry, and the nation had better not wait too long to decide on what should be done, otherwise we may lose our technical leadership in civil aviation.

3.3 Environmentally Acceptable and Economically Feasible

3.3.1 Economics

One aspect of economic feasibility, is that trip durations aboard the HSCT will have to be significantly shorter than those presently experienced aboard subsonic transports. Trips from the west coast of the U.S. to Japan will need to be reduced from about 10 hours to just over 4 hours (Figure 20), and London to Tokyo will need to drop from around 13 hours to 6 to 7 hours.

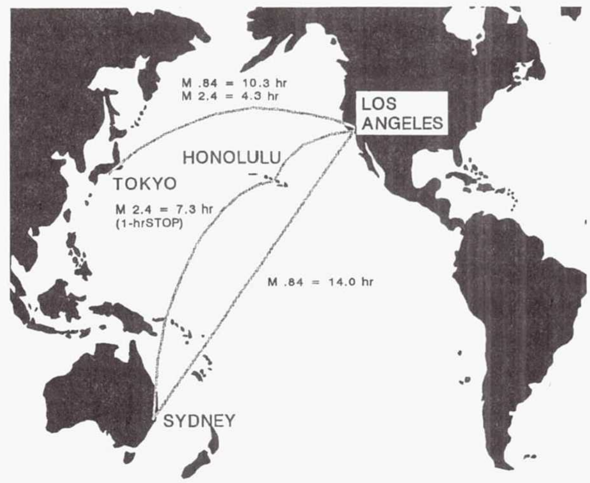


Figure 20. HSCT trip time comparison to a subsonic long-range jet transport. (Source: Boeing Commercial Airplane Group, High Speed Civil Transport: Program Review, 8)

For the HSCT to be economically viable, it must be able to provide a reasonable financial return for both the aircraft manufacturer and the airlines. Any increases in operation or ownership costs of the HSCT over a subsonic transport with the same route, must be overcome largely due to increasing its productivity due to its higher speed. Basically, it would need to fly and be turned around on the same route twice in the time it would take a subsonic transport to fly and be turned around once.

The impact of technology on the economic viability of the HSCT is shown in Figure 21. This Boeing evaluation shows that with today's technology, the total worldwide fleet estimation would be less than 300 aircraft, which would not be an adequate number of aircraft to ensure a profitable program. By delaying, and using technology which would be available for aircraft certification after the year 2000, an HSCT fleet of over 650 aircraft could be supported.

The HSCT will be required to carry up to two to three times the number of passengers as does the

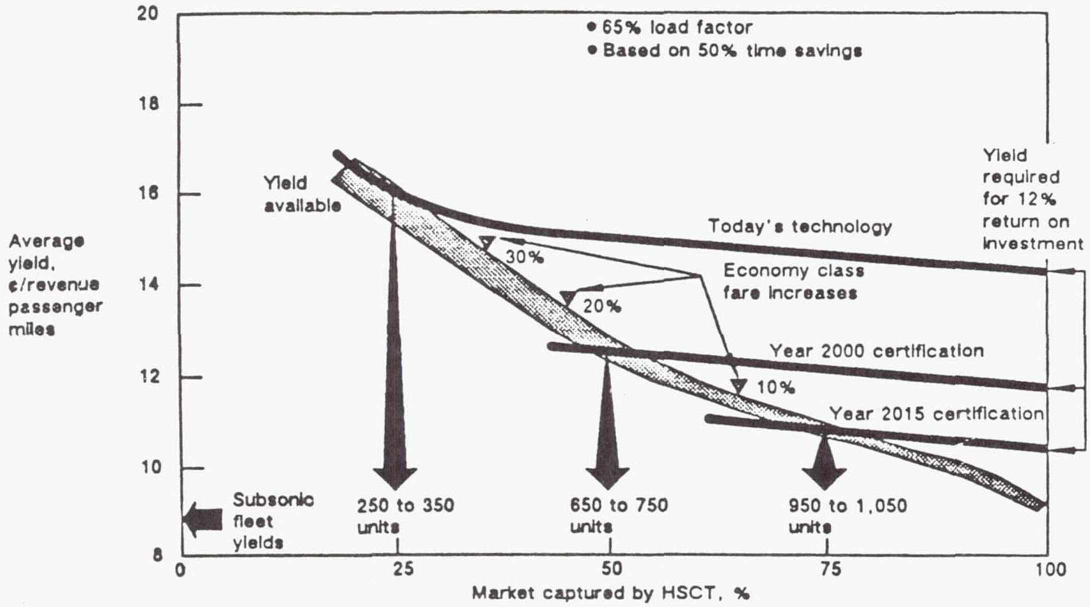


Figure 21. Economic Viability - The impact of technology on fleet size based on a Mach 2.4, 247-seat aircraft design with a 9260 km (5,000 nmi) range. (Source: Boeing Commercial Airplanes, High-Speed Civil Transport Study, NASA CR-4234, 29)

Concorde, at less than one-seventh the cost per passenger mile, and have roughly twice its range (Figure 27). Economics are also factored in when replacements are considered. It has been estimated that a significant number of long-range aircraft replacements will be needed after the year 2000. The expected market growth combined with a need for replacements points towards an obvious need for the HSCT, if it can meet the above criteria.

3.3.2 Environment

The Boeing and Douglas studies, identified earlier, have also determined that the demand for an HSCT type aircraft will only materialize if it meets allowable standards of airport noise, has no harmful effects on the atmosphere and is economically competitive with future long-haul subsonic airliners. R.M. McKinlay, managing director of British Aerospace Commercial Aircraft, has said that "The airport noise level has got to be no more than subsonic aircraft." Lowrie, Denning and Gupta reiterate that "The major environmental hazards...with the Supersonic Transport are the noise near the airports, sonic booms and atmospheric pollution." and that "Both the noise and contamination are directly associated with the propulsion system." The ICAO notes: "Any new SST aircraft will need to have economically acceptable operating costs...[and] meet exacting environmental requirements in the noise, sonic boom and emissions areas."

3.3.3 Noise

The environmental acceptability, including community noise, is a major issue needing resolution if the HSCT is to operate along with the existing subsonic fleet. For all present and future commercial transport designs, Federal

Aviation Administration (FAA) regulations will impact the engine size, the addition of noise suppression devices, and operational characteristics, all affecting the economic viability of the next generation SST.

Increasing concern over the effect of airport noise (coinciding with increased jet aircraft usage) has created increasingly more stringent regulation of aircraft noise levels. Engen, in his Report to Congress, states the aircraft community noise problem has been and is still being reduced. The noise reduction has primarily been due to the Federal Aviation Administration's implementation of FAR 36. Certification requirements (Stages I,II,III) under FAR 36 , have over the last 20 years, required commercial subsonic transports to meet steadily decreasing noise levels. Present day civil transports, both domestic and foreign, must meet either FAR 36 Stage II or Stage III (depending on the aircraft's certification date, weight, and number of engines). Eventually, all subsonic civil transport carriers will be required to operate their aircraft below FAR 36 Stage III noise levels. NASA is committed to help the U.S. aerospace industry achieve FAR 36 Stage III operation for the HSCT.

Figure 22 shows noise certification trends for the majority of western built civil transports. The noise environment following the elimination of all Stage II aircraft will consist of only Stage III subsonic aircraft, and the Concord (which has a special operational waiver to operate in the U.S.). This is the noise environment which the HSCT will have to operate.

NASA sponsored a workshop, in June of 1988, on community noise related issues pertinent to a high speed civil transport. One conclusion coming out of the workshop was that meeting the present noise regulations of FAR 36 Stage III would pose a "significant technical challenge" for the HSCT. Nihart and Brown estimate the HSCT, will at takeoff, exceed FAR 36 Stage III

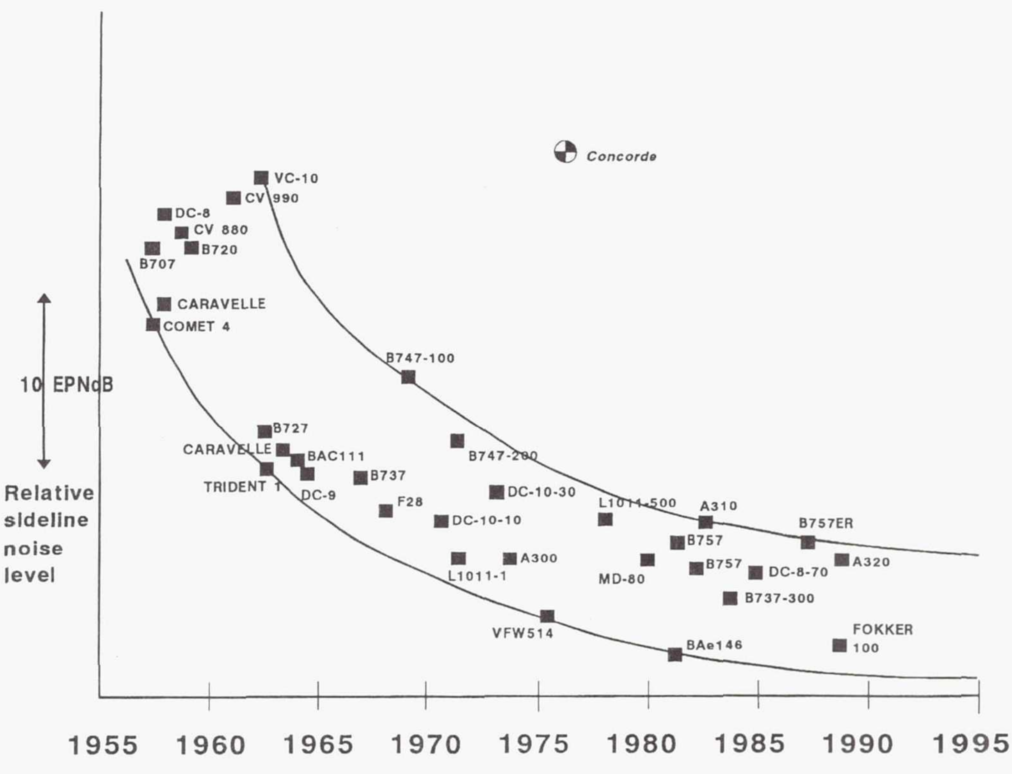


Figure 22. Noise certification trends. (Source: Rolls Royce)

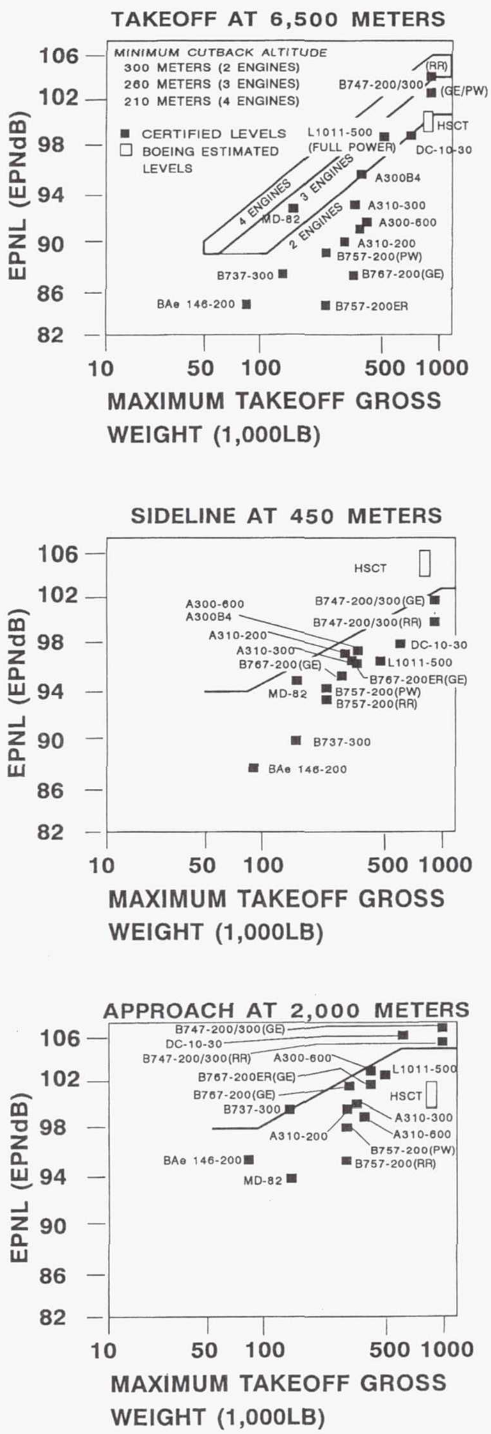


Figure 23. Anticipated community noise levels of an HSCT. (Source: Nihart, Gene C., Brown, Jeffrey J., Supersonic Propulsion Systems and Community Noise suppression Concepts, AIAA-88-2986, 6)

limits if its exhaust is left untreated (Figure 23). Present day noise reduction technology would probably be able to get existing jet engine noise levels to within about 6 dB's of FAR 36 Stage III. Figure 24 shows the sideline noise generated by the Concorde compared with FAR 36 Stage II and III requirements. Figure 24 also shows the advances made through the SCR/VCE program, and where the HSCT will need to be.

Meeting these stringent noise requirements will be difficult with the engine cycles required for supersonic flight. Unlike the high by-pass ratio turbofan engines used by subsonic transports, the engines used by the HSCT will produce high-velocity jet exhaust flows, which are inherently noisy. Engine and exhaust systems (nozzles) which can entrain and mix colder ambient air with the hot exhaust flow can reduce the maximum exit velocity, and therefore reduce the noise generated. Acoustic treatments can also be applied inside of the nozzle to lower or alter the noise, and make it less objectionable. The prime objective of these low noise nozzle concepts is to lower the noise while minimizing the additional weight and thrust loss, associated with the longer and more complex nozzles.

Successful noise reduction techniques will need to be applied to the HSCT in order to permit it to use existing "subsonic airports," like those identified in Figure 25. Without additional noise suppression of the HSCT, it might be limited to flying out of remote airports or special "spaceports." The bottom line is the HSCT will have to produce noise levels which are acceptable to the communities around these airports. The aircraft generated noise levels are typically the most annoying in these communities.

3.3.4 Sonic Boom

The HSCT would benefit economically from supersonic operation over land (the cruise speed of the HSCT will be around Mach 2.4). But,

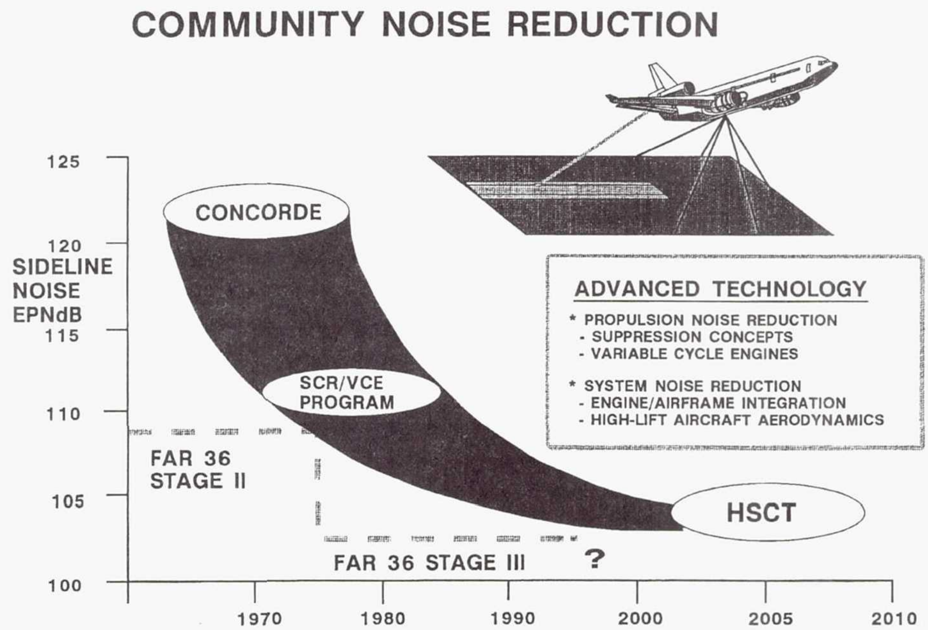


Figure 24. Community noise reduction comparing the Concorde with SCR/VCE technology, and the Stage III goal for the HSCT.

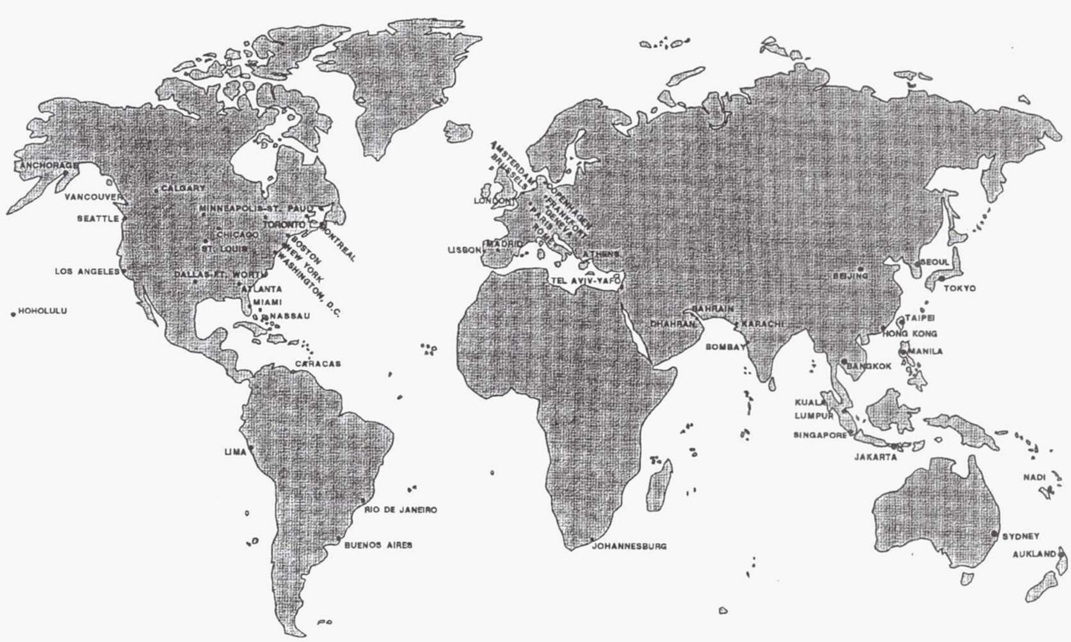


Figure 25. Cities used in the Boeing route system study, and representative of long range commercial airports suitable for an HSCT. (Source: Boeing Commercial Airplane Group, High Speed Civil Transport: Program Review, 7)

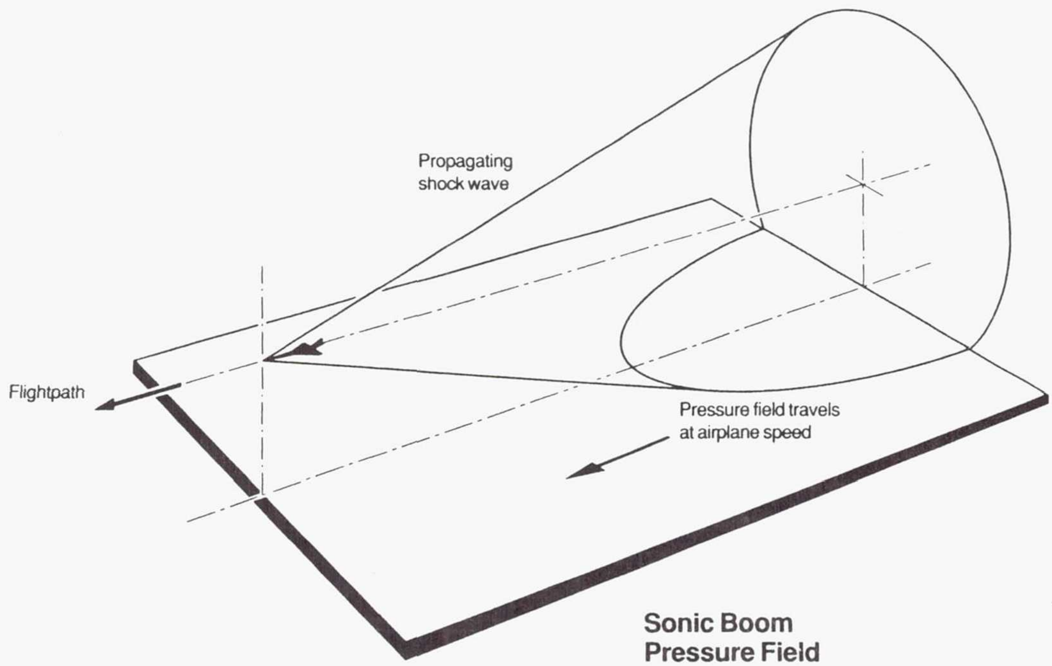


Figure 26. Sonic boom pressure field and Mach cone is generated from an aircraft flying faster than the speed of sound (Mach=1.0).

when an aircraft exceeds the speed of sound (Mach=1.0) and flies at supersonic speeds, the aircraft produces shock waves which can propagate to the ground, Figure 26. These shock waves create sudden pressure changes, which creates a sonic boom. The loud noise associated with supersonic flight is usually severe enough to be objectionable to a person on the ground. The sonic-boom overpressure level of an HSCT designed for low weight and optimum aerodynamic performance will be unacceptably high for overland flight in populated areas. As a result, the Concorde has been limited to subsonic speeds over land in the U.S. Supersonic flight is therefore limited to flying high enough, and over water to avoid populated areas, and thus avoid sonic boom complaints.

There are quite a few inland international airports which could be serviced by an HSCT. Until the sonic boom generated by the aircraft can be modified to be less objectionable, the HSCT will have to decelerate to subsonic speeds over populated land areas. The HSCT needs to be optimized for supersonic flight, and will pay a performance penalty when forced to fly a significant portion of its flight subsonically. The amount of over land flight can affect the economic viability of an HSCT fleet. This in turn, could limit the number of airports serviced by it, and therefore affect the total fleet size.

The HSCT can regain some of this economic penalty by being able to fly at reduced supersonic speeds over land through shaping of the aircraft, and other advanced boom reduction methods. Studies are being pursued to look at several options for reducing the amplitude of the sonic boom shock wave to a target overpressure of 1.0 lb/ft^2. This level, with typical rise times, would result in potentially acceptable sound

levels and allow for roughly Mach 1.5 operation in restricted "supersonic" corridors over land.

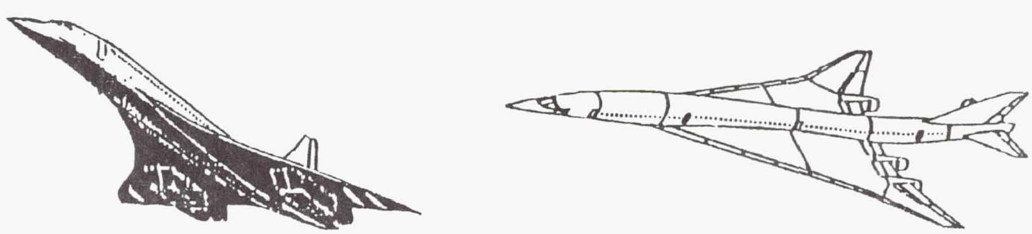
3.3.5 Atmospheric/Emissions

The HSCT must have minimal effects on the atmosphere, specifically it must have no significant effect on the stratospheric ozone layer. The HSCT will cruise at altitudes of between 88,550 and 101,430 meters (55,000-63,000 feet), which also corresponds to the lower region of the ozone layer. Several concerns have arisen following the discovery that by-products generated from the combustion of hydrocarbon fuels will react with ozone.

Studies have shown that nitrogen oxides (NOx) and other emissions from aircraft flying in the stratosphere have the potential of damaging the ozone layer. To ensure that emissions from the high-flying jet engines will not harm the ozone layer, new combustion concepts will have to be developed. Research is showing that jet engine combustors can be designed for low production of NOx. These low NOx combustor concepts will achieve low emission levels by controlling the burning process very precisely.

The HSCT will need to be designed for optimum aerodynamic and economic performance throughout its entire flight regime. Figure 27 dramatically shows the performance differential between the 1960's technology Concorde and the proposed HSCT. Noise requirements which are too strict will severely affect its performance and may limit the economic viability of this aircraft, consideration may need to be applied towards this end.

SUPERSONIC TRANSPORT CHARACTERISTICS



Concorde		HSCT Goals
2.0	Mach Number	2.4
3000	Range (n. mi.)	5000-6500
100	Payload (passengers)	250-300
400,000	Weight (lb.)	750,000
87	Required Revenue (¢/RPM)	10
Premium	Fare Levels	Standard
Exempt	Community Noise Standard	FAR 36 - Stage III
20	Emissions Index (gm/Kg fuel)	3-8 (at HSCT efficiency)

Figure 27. Comparison of the operational characteristics of the Concorde and the operational goals of the HSCT.

3.4 NASA's HSCT Program

NASA and industry are conducting research to develop technologies for application to the HSCT. Figure 28 shows the approach being taken by NASA and industry to achieve an HSCT with an Initial Operational Capability (IOC) of 2005. NASA will be spending $284 million over the next six years to explore ways to reduce the anticipated environmental and economic technical challenges, Figure 29. This HSCT research is being conducted under the auspices of the High-Speed Research Program (HSR).

The goals of the HSR program Phase I, are focused on the three environmental issues - atmospheric effects, airport community noise, and sonic booms, Figure 30. These environmental issues are basic concerns which require better understanding before additional economic efforts are initiated. Figure 31 shows a milestone summary of efforts under Phase I. Assessment of atmospheric effects of HSCT operation will be determined and a suitable set of standards will be established. All individual Phase I efforts will be closely coordinated with systems studies which serve as a necessary tool for understanding the effects of individual and integrated technologies on overall environmental compatibility, as well as determining the economic viability of HSCT concepts. Combustor research and technology efforts will be directed at reducing emissions. A significant effort will also be directed at propulsion source noise reduction. Figure 32 provides a summary of the Phase I content.

A successful conclusion of the interrelated research efforts under Phase I will demonstrate the following. For emissions, Phase I will demonstrate the feasibility of 90% NOx reduction, show the validity of HSCT ozone effects predictions, and the determination of acceptable emissions levels. For airport community noise, Phase I will demonstrate the

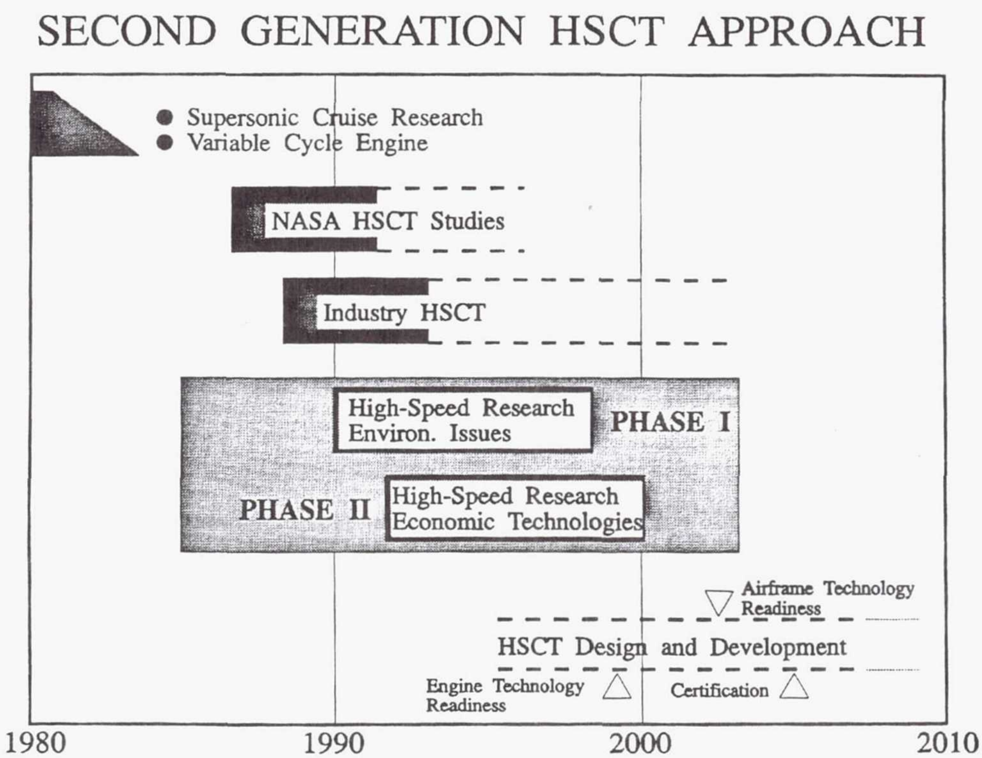


Figure 28. HSCT approach and schedule.

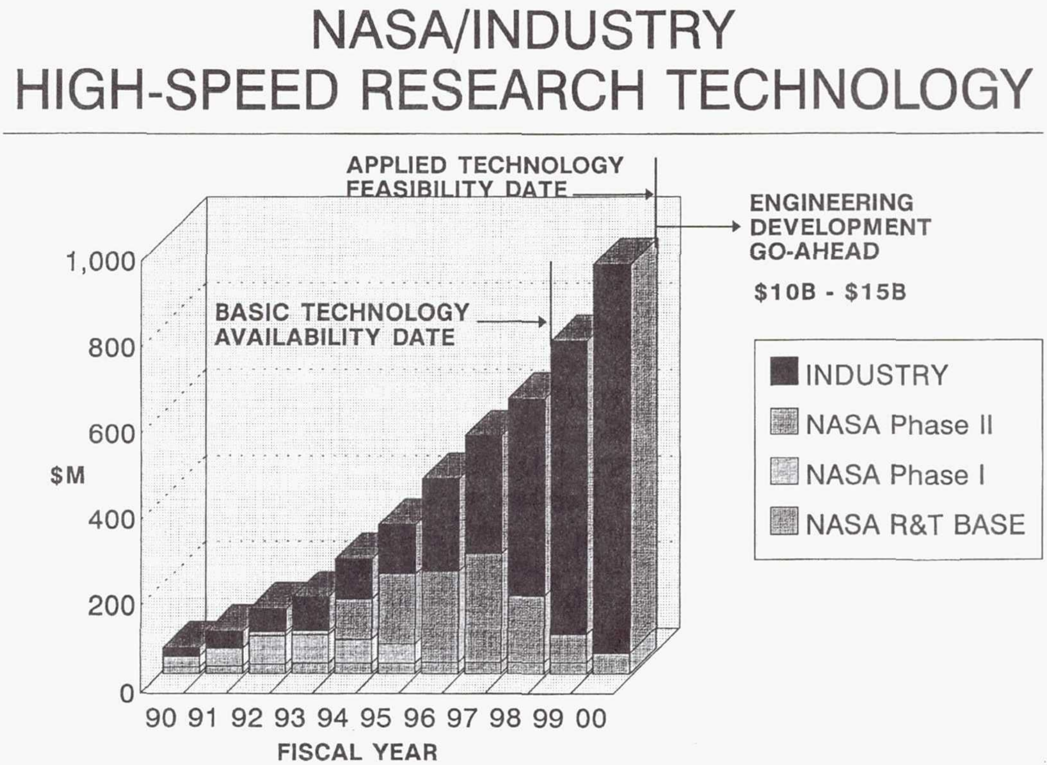
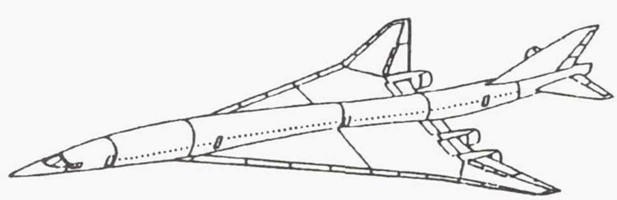


Figure 29. NASA/Industry High-Speed Research anticipated funding requirements.

PROGRAM GOALS



- **STRATOSPHERIC OZONE**
  - DEVELOP PREDICTIONS OF HSCT OZONE EFFECTS
  - DETERMINE FEASIBLE NO_x REDUCTION LEVELS
  - PROVIDE TECHNICAL BASIS FOR ACCEPTABILITY CRITERIA
- **AIRPORT COMMUNITY NOISE**
  - DETERMINE FEASIBILITY OF ECONOMICAL COMPLIANCE WITH FAR 36-III
- **SONIC BOOM**
  - DEVELOP HSCT SONIC BOOM PREDICTIONS
  - DETERMINE FEASIBLE SONIC BOOM REDUCTION LEVELS
  - PROVIDE TECHNICAL BASIS FOR ACCEPTABILITY CRITERIA

Figure 30. HSR Phase I program goals.

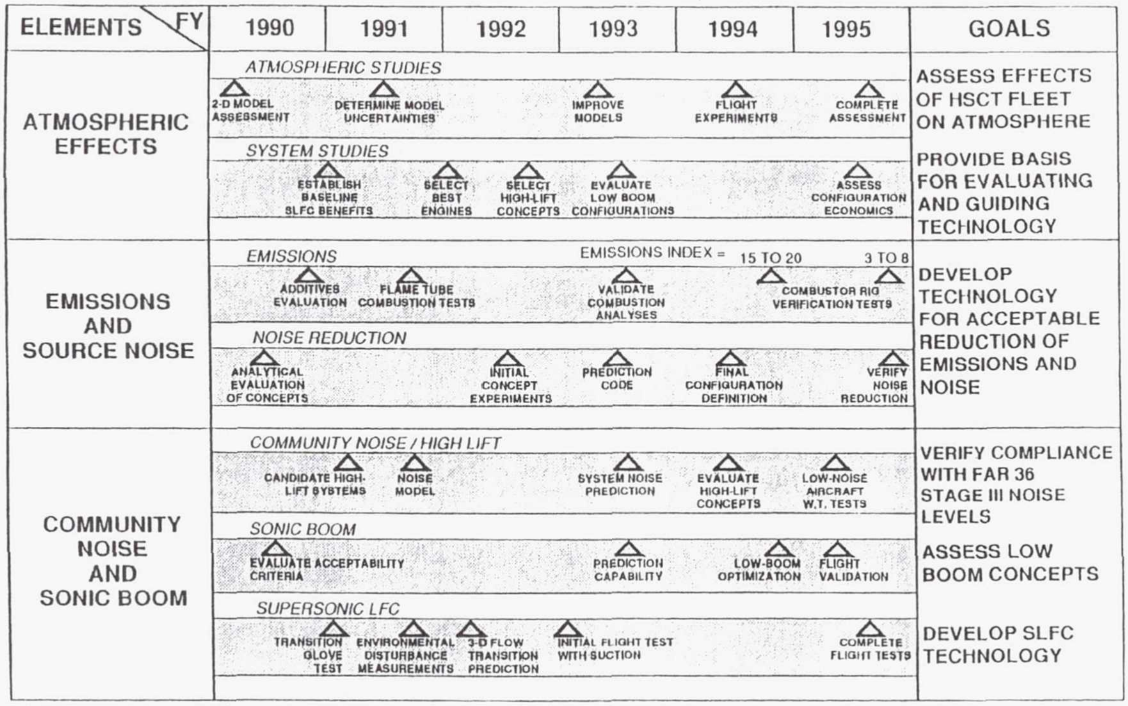


Figure 31. Milestone summary for Phase I of the High-Speed Research Program.

ATMOSPHERIC EFFECTS
- ATMOSPHERIC STUDIES
- SYSTEMS STUDIES

EMISSIONS AND SOURCE NOISE
- EMISSION REDUCTION
- PROPULSION NOISE REDUCTION

COMMUNITY NOISE AND SONIC BOOM
- COMMUNITY NOISE REDUCTION AND HIGH-LIFT RESEARCH
- SONIC BOOM
- SUPERSONIC LAMINAR-FLOW CONTROL

Figure 32. High-Speed Research Program Phase I program content.

feasibility of economically viable compliance with FAR 36 Stage III regulations. And for sonic booms, Phase I will demonstrate the feasibility of acceptable supersonic overflight or economic viability assuming subsonic overflight restrictions.

Under Phase I, NASA and industry studies will have defined the necessary technological requirements for a viable HSCT. And, based on the current state-of-technology, the HSR Phase II program will be initiated in order to provide an informed basis for a go-ahead decision on an HSCT for certification in 2005. The main technology elements of Phase II are shown in Figure 33. The planned NASA/industry technology program would result in the required technologies being availability in the 1998-1999 time frame, Figure 34. This technology availability is necessary to enable the U.S. industry to continue technology demonstration efforts and manufacturing validations prior to a year 2000 go-ahead decision.

One of the key pacing technology issues is the availability of high-temperature, lightweight, durable propulsion materials. NASA's ongoing HITEMP engine materials program will provide the basis for the development of advanced composite materials required for combustor and nozzle components of any future HSCT engine. The Enabling Propulsion Materials effort is planned to start in FY92, and interact directly with component research efforts.

The remainder of the Phase II program will start in FY93 with the Critical Component Technology and Propulsion Systems Demonstrations efforts, Figure 35. The HITEMP and HSR Phase I programs will provide the foundation for the proposed Phase II program. The propulsion elements of HSR Phase II would demonstrate HSCT propulsion technology readiness initially through large-scale testing of critical components like the inlet, fan, combustor, and nozzle, Figure 36. These components would then be combined with an available core engine in propulsion systems technology demonstrations at both low-speed (takeoff) and high-speed (supersonic cruise) conditions.

3.5 Summing the Challenge

The previous sections have shown the need, and thus the reason why the planning and research for the HSCT has started. Fielding this aircraft will not be easy, environmental and economic hurdles stand in the way. Much time, money and effort will be poured into this project. The amount of the effort being applied to this program raises the issue, what happens if the HSCT can not meet the noise requirements of FAR 36 Stage III, the low emissions levels, or viable economic operation? The HSCT will factor heavily in the nation's economic future. How will the noise regulations and technical challenges affect our ability to field this aircraft at this time? And what are the challenges if the U.S. doesn't field an HSCT before a foreign consortium does?

HIGH-SPEED RESEARCH PHASE II

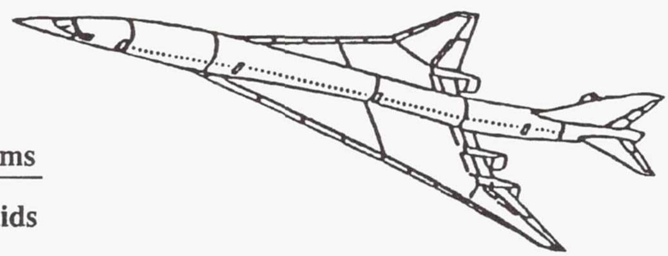
TECHNOLOGY ELEMENTS

Airframe

- **Aerodynamic performance & integration**
- **Airframe structures technology**

Propulsion

- **Critical propulsion components**
- **Enabling propulsion materials**
- **Propulsion system demonstration**



Flight Deck Systems

- **Restricted visibility aids**
- **Constrained space cockpit**

Figure 33. High-Speed Research Phase II technology elements.

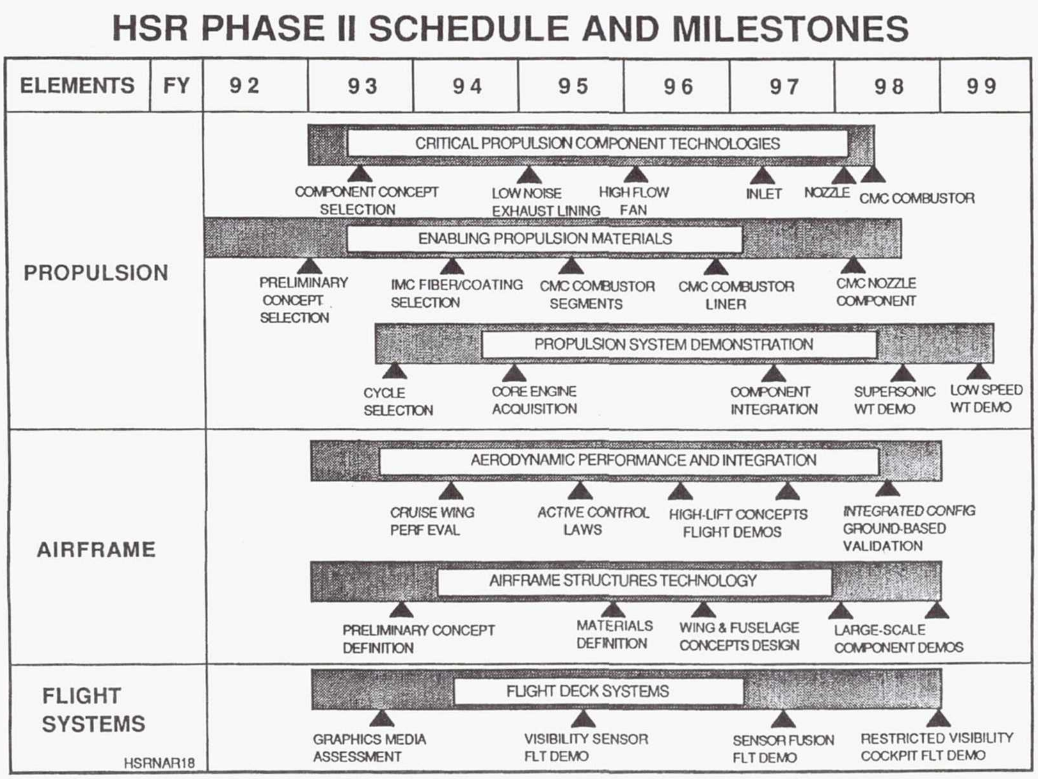


Figure 34. HSR Phase II schedule and milestones.

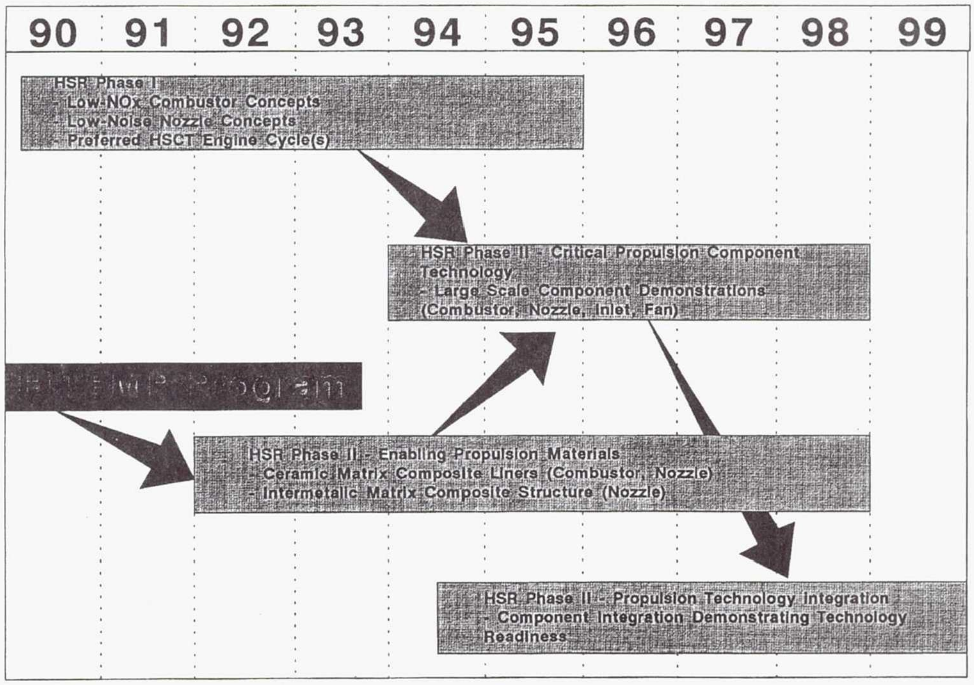


Figure 35. NASA High-Speed Research plan propulsion elements.

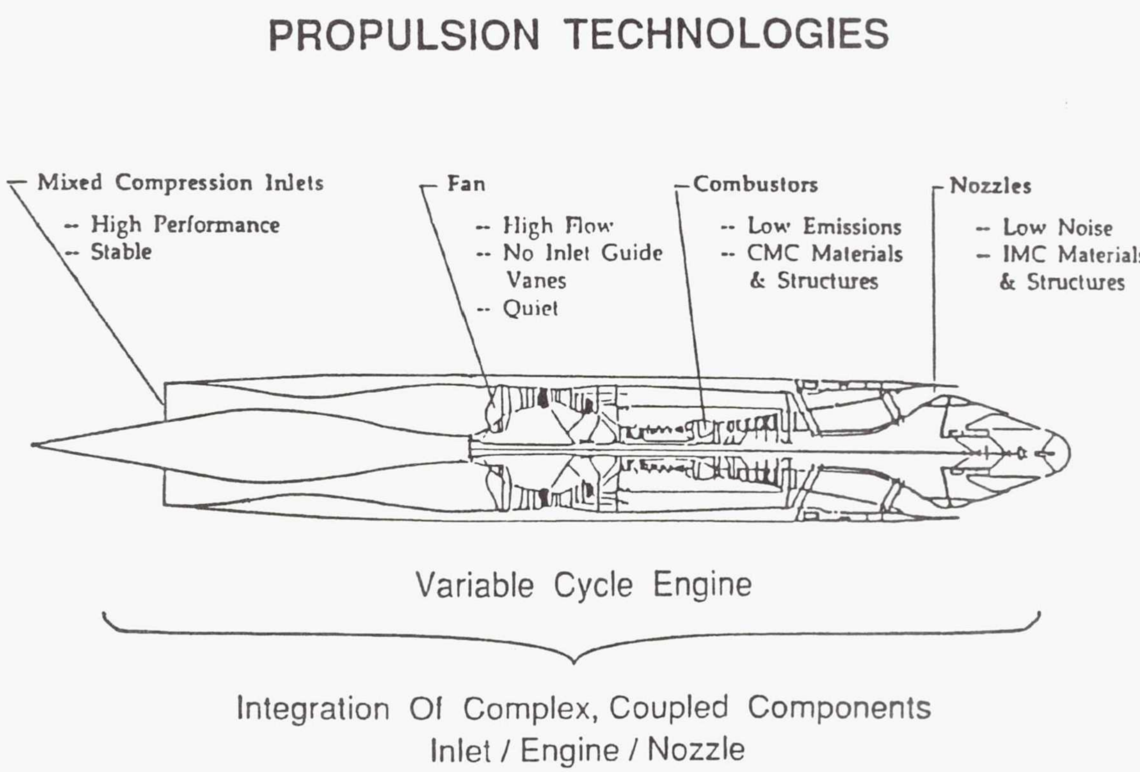


Figure 36. Propulsion technologies being addressed under HSR Phase II.

4.0 PROPULSION-AIRFRAME INTEGRATION

Why a bibliography on propulsion-airframe integration (PAI)? PAI is a multidisciplinary systems integration activity. It spans many diverse fields including: inlets, nozzles, engine cycles, acoustics, high lift devices, aerodynamics, sonic boom, materials, and structures.

Traditionally, most aircraft have been designed by component build-up, meaning that individual parts of the aircraft were designed and tested, then later assembled into a unit. This is not adequate for a tightly-integrated system such as the HSCT, with many mutual interaction effects between components, and very demanding performance requirements. The aircraft performance, economics, and environmental acceptability can be adversely affected if the integration of the propulsion system and airframe is not addressed properly, and in a timely manner. Therefore, components must be designed by taking into consideration any installation effects, both favorable and adverse, in addition to optimizing critical component technologies.

4.1 Planning for PAI activities

To initiate the High Speed Research Program (HSRP) PAI planning activities, a preliminary PAI meeting was held in June 1990 for industry to provide NASA with an update on PAI technology issues, developments and requirements since the Supersonic Cruise Research Program. A key objective of this meeting was to identify PAI issues which will affect the achievement of the HSR Phase I program.

Some particular examples, by no means a complete list, of PAI related issues are:

***2D vs. axisymmetric nozzles**

***CFD validation of nacelle placement/shape database**

***2D vs. axisymmetric inlets and nacelles**

***inlet unstart effects, cross-unstarts**

-cruise mach number effects

-installation effects on low noise nozzles

-installation effects on inlet, due to wing boundary layer, upstream flow disturbances (e.g. landing gear), etc.

The four issues identified above with asterisks were deemed as "high priority" issues. For example, achievement of take-off noise levels below FAR 36 Stage III is a key Phase I goal, but PAI issues such as the wing/flap trailing edge flowfield interactions with nozzles and their acoustic suppression characteristics has yet to be identified. Looking back over the last 10 years has seen considerable progress in the area of computational fluid dynamics (CFD) codes and analysis. But, little experimental validation has been attempted to assure their applicability to HSCT design and prediction. Nacelle placement and shape trade-offs, which affect system drag and lift, require updating from earlier research activities under the SCAR, SCR, and AST programs. This database needs to be updated with information reflecting today's aerodynamics and cruise Mach number. The final high priority issue is inlet sellection and performance. For cruise Mach numbers greater than 2.2, a mixed-compression inlet will be required to get suitable performance and inlet pressure recovery. Mixed-compression inlets, however, are not as stable as external compression inlets. If inlet unstart can not be properly handled, then the cruise Mach number sellection can potentially become a PAI issue. As a direct

consequence of this meeting, several in-house and contracted efforts have been initiated.

In terms of the NASA HSR program, the ultimate objective for Propulsion/Airframe Integration is to demonstrate the technologies for achievement of these goals on a "single" integrated configuration. The scope and goals PAI studies have been defined in a 1991 NASA-industry meeting as follows:

-nacelle-airframe interference and interactions (lift & drag)

-flowfield effects on internal performance

-nacelle-airframe effects on acoustics

First is nacelle-airframe interference and interactions where installation effects on lift and drag are addressed. For example, the flow around the propulsion system can influence the local pressure field on the wing and result in a change in the lift and drag characteristics of the wing. The goal would be to achieve an integrated system drag and/or lift values to be better than the combination of their isolated values. Second is the impact of the external flowfield on the propulsion system performance and stability. An example would be wing or other aircraft component (like high-lift devices, accessory packages, or strucures) effects on inlet and nozzle performance. Third is the impact of nacelle and and airframe flows on nozzle acoustic characteristics. For example, the wing flowfield effect on the nozzle take-off acoustic suppression. An ideal concept would be a suppressor design which can take advantage of both the wing/nacelle flowfield characteristics and geometric shielding.

The NASA goals in the PAI aspect of the program were also defined:

-experimentally demonstrate PAI technologies on an integrated configuration

Specific technical goals have been identified for the airframe and propulsion systems. The aerodynamic goals are listed below:

-supersonic cruise lift/drag = 10

-transonic lift/drag > 15

-takeoff lift/drag = 10

And, the following two goals were identified for the propulsion system:

-exceeds FAR 36 Stage III noise regulations

-favorable impact on inlet and nozzle performance

The deliverable products of research efforts in these areas are listed below.

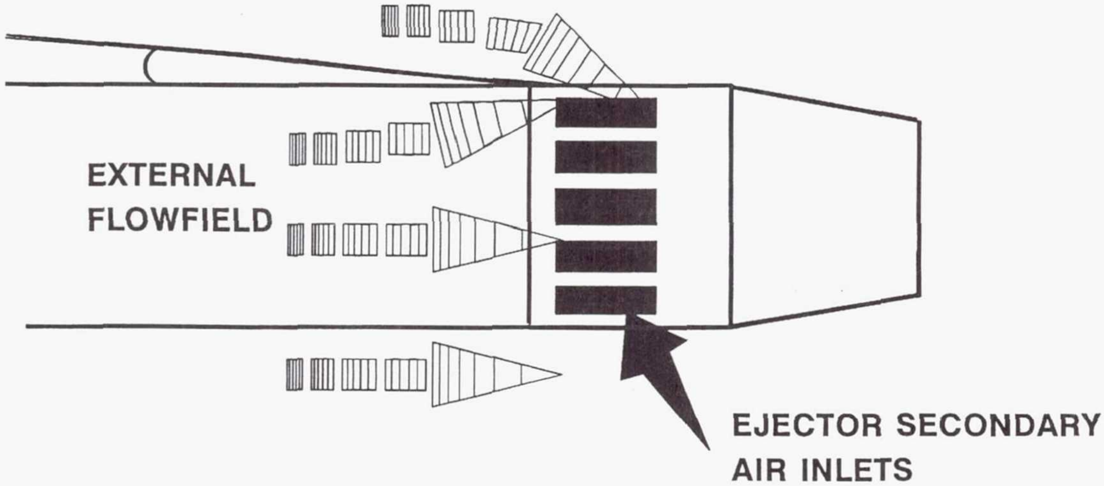
-validated airframe/nacelle design procedures and techniques

-diagnostic procedures / test techniques

-experimental database for analysis code validation and design trades

4.2 NASA PAI Activities

At the NASA Lewis Research Center, low noise nozzles are aggressively being pursued for take-off conditions under the HSR Phase I program. Specifically, the research is focussing on ejector-type flow augmentation schemes to reduce jet velocities and thereby reduce noise. In current study designs as depicted in this Figure 37, these ejector-type flow augmentors require secondary air intakes which are located aft of the trailing wing/flap trailing edge. As a consequence, the flowfield at the ejector secondary air intakes will



- **WING AND TRAILING-EDGE FLAPS ALTER NOZZLE EXTERNAL AND EJECTOR-INLET FLOWFIELD.**
- **HENCE, ACOUSTIC SUPRESSION CHARACTERISTICS WILL BE ALTERED.**

Figure 37. PAI affects ejector nozzle acoustic characteristics by influencing the flow going into the nozzle's ejector inlets.

likely be quite complex and certainly different than what occurs around the isolated nozzle Jet Exit Rig (JER) currently being used to study nozzle acoustics. The ejector inlet performance will be affected by the integration, subsequently, the acoustic suppression characteristics of the nozzle/ejector system will be affected.

Experimental aero-performance and acoustic evaluations of axisymmetric and 2D nozzles are planned for Fall of 1991 at Lewis. The basic problem discussed in the previous paragraph can be addressed on a preliminary basis by adding a wing-section to these nozzle tests as depicted in the Figure 38. This wing would have appropriate sweep and high-lift devices at the leading and trailing edges to allow it to be generically representative of an HSCT design. The experiment will include variable flap settings and the ability to vary the position of the wing from the secondary ejector inlets and jet exit rig. Planned measurements include not only pressure, flowfield, and acoustic measurements but may also include LDV. From such an experiment, we expect to begin development of an PAI experimental database for aero performance, acoustic, and flowfield analyses for wing/nozzles. Specifically, the results of this experiment will be used to validate CFD codes for nozzle-wing-nacelle type flows. The main challenge is to combine analysis of internal and external flows about complex configurations; the code can then be applied to more realistic configurations. For this a generic wing/nozzle configuration, researchers also hope to determine the first-order effects on the acoustic characteristics of ejector nozzles due to non-uniform external flow into the ejectors and an early assessment ejector nozzle aerodynamic performance as a result of installation.

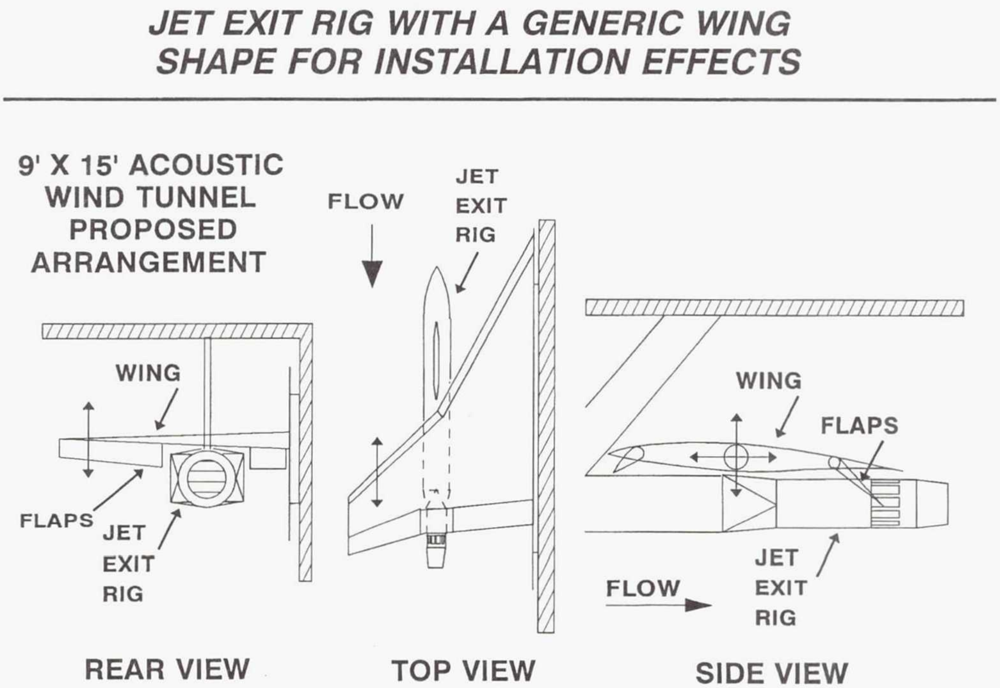


Figure 38. Jet exit nozzle test rig with a generic HSCT wing planform for installations effects testing.

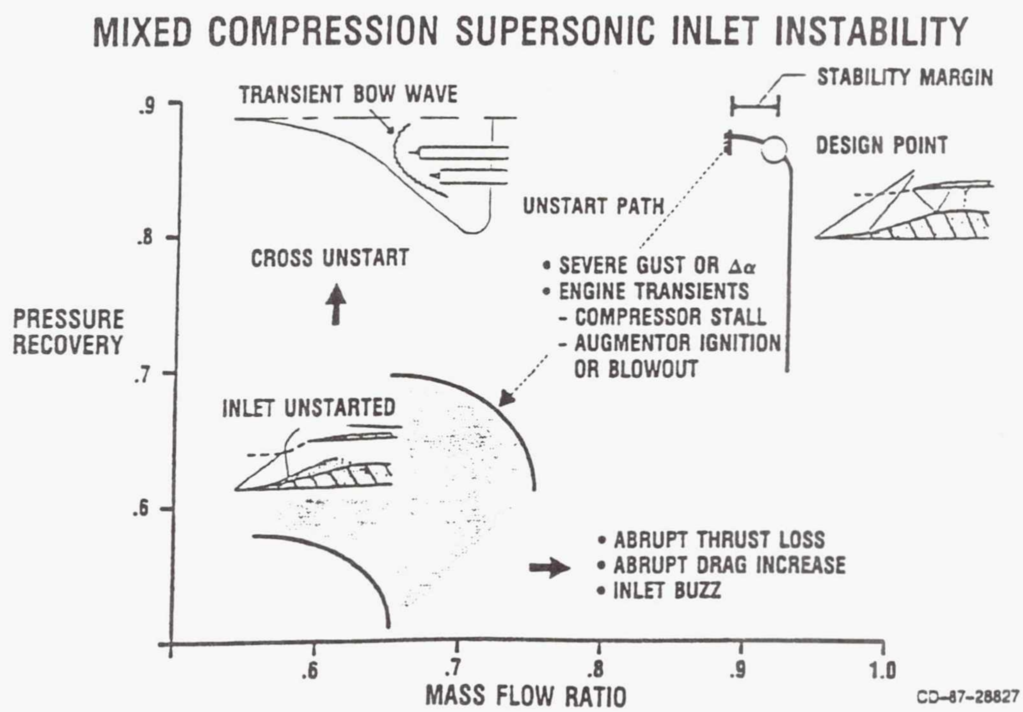


Figure 39. Mixed compression supersonic inlet instability, showing pressure recovery versus inlet mass flow rate.

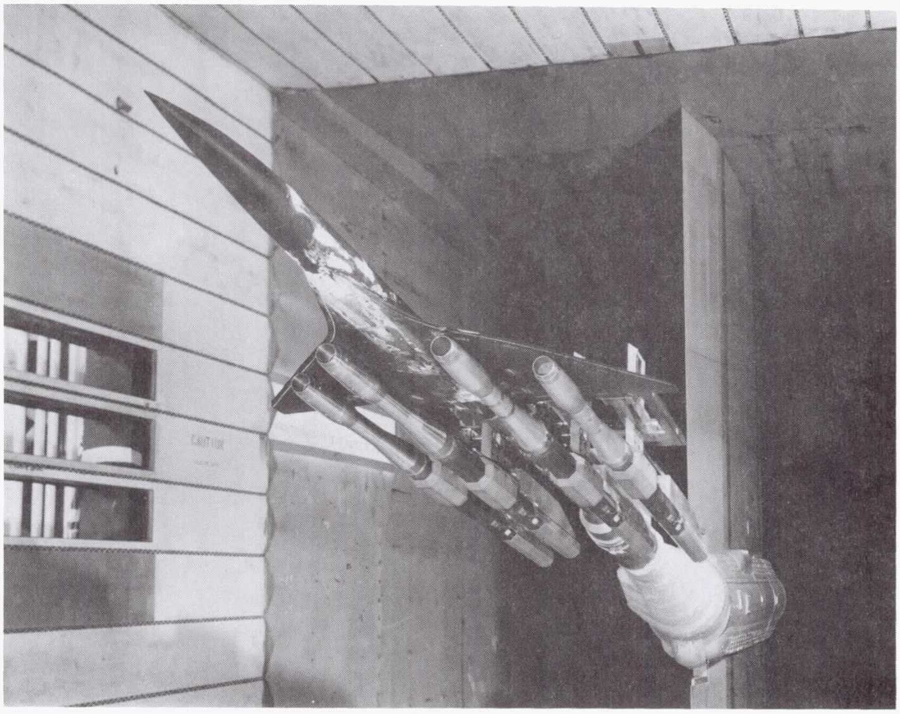


Figure 40. The Boeing SA1150 model is shown in the Ames 11- by 11- Foot Transonic Wind Tunnel where nacelle placement tests were conducted to determine interferences effects.

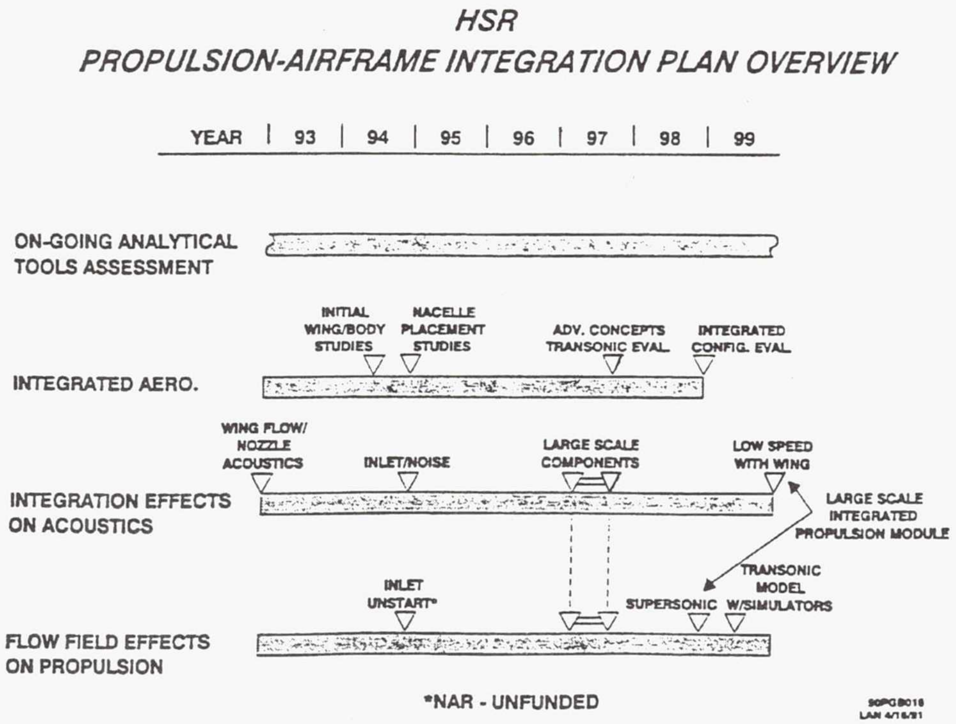


Figure 41. HSR propulsion/airframe integration plan overview.

NASA Langley has been very instrumental in the design of the generic HSCT wing planform for the above mentioned wing/nozzle integration test. Researchers at Langley have been actively pursuing high-lift devices and lift enhancement techniques like Laminar Flow Control (LFC), as well. They are also quite invlolved with HSCT aircraft systems studies.

Figure 39 introduces the subject of mixed compression supersonic inlet unstart which leads to the concern regarding certification of mixed compression inlets. Above cruise Mach numbers of approximately 2.2, mixed compression inlets provide superior performance over other types. A mixed compression supersonic inlet has a portion of its supersonic diffusion (compression) occur inside of the inlet cowl lip. Two ''grossly'' stable conditions can occur for this type of design. The inlet normal shock is contained just downstream of the inlet throat for the first, and desirable, condition. The second condition occurs when this normal shock is expelled from the inlet throat and is either subsonic or choked. This second condition results in poor inlet performance, which also may be unstable (buzz), and asymmetric drag and/or lift conditions on the aircraft. Transition from the first to the second condition, called an ''unstart,'' can be caused by an external event such as a gust or angle of attack change, or by engine airflow transients. Passenger safety and comfort issues as well as aircraft stability and control problems can result if the consequences of the unstart are severe. Considerable debate has occurred on this subject because of the potential impact on cruise Mach number, NASA Langley has been studying this problem in some depth.

A propulsion airframe interference test was conducted in the Ames 11- by 11-Foot Transonic Wind Tunnel in 1973, Figure 40. The purpose of the test was to measure detailed interference force and pressure data on a representative supersonic wing-body-nacelle combination at transonic speeds. The aerodynamic model is based on Boeing's model SA1150 and is a delta wing-body configuration at 0.024 scale. All hardware associated with the model has been recovered and is in the process of being refurbished. Of the four individual nacelles supported beneath the wing-body model, the two on the left-hand side were pressure instrumented, and the other two were force instrumented. The four nacelles were supported beneath the wing-body independently by the nacelle support system, providing flexibility of positioning the nacelles relative to the wing-body and each other. Future PAI plans associated with this model and testing in the Ames 9- by 7-Foot Wind Tunnel scheduled for June 1992.

Looking ahead to the 1993 through 1999 time period and HSR Phase 2, a preliminary view of the general scope and milestones for PAI are shown in this Figure 41. The basic concepts shown in this figure were developed as part of the HSR Non-Advocate Review effort. (The Non-Advocate Review project plan identified the basic scope for the overall HSR Phase 2 Program.) This preliminary PAI plan identifies an on-going analytical tools/CFD codes assessment occurring in parallel with the experimental portions of the program. The milestone times are meant to be indicative of experimental knowledge availability in support of these analyses and as validation of technologies and concepts. For the purposes of this figure, the main experimental elements of the program have been divided between three categories of PAI identified above. At the conclusion of the plan (1998/9), several ''systems'' experiments would be accomplished including integrated tests of the inlet, engine and nozzle at supersonic speeds and at low speed (take-off). Transonic tests would be accomplished using a simulator powered sub-scale model.

Industry will decide on the final HSCT requirements, and NASA will help cultivate the technology base for its development. In this regard, the NASA HSR PAI role is viewed as

delivering the following: validated airframe and nacelle design procedures and methodologies, validated diagnostic procedures and test techniques, and an experimental knowledge base for analytical code(s) validation and for design trades. In conclusion, the HSR Propulsion/ Airframe Integration is viewed as critical to a successful HSCT. HSR Phase I goals which could be affected by PAI issues are being addressed. And finally, long-lead PAI activities have been identified and steps are being taken to initiate them.

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1.1 GENERAL SURVEYS

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Two U.S. companies are continuing the efforts of a small-scale 1987 NASA project on high-speed civil transport (HSCT) design which would reduce Los Angeles-Tokyo travel time from 10.3h to 4.3h. Considerations for cost, productivity, and a limited acceptance of supersonic boom have caused Boeing to focus on Mach numbers between 2.0 and 2.4 for overseas travel, and at Mach 0.9-1.1 for overland. Market projections have caused McDonnell Douglas to concentrate on low-boom designs to facilitate overland travel, while Boeing plans to target overseas routes where boom noise is more acceptable. Due to heating considerations, high-temperature thermoplastic resins and improved thermosetting matrixes are being considered for HSCT airframe construction. Landing and takeoff noise are to be controlled by limiting the overall weight, by improving the low-speed aerodynamics, and by engine silencing. A naturally aspirated, coannular nozzle and an inverse coannular exhaust are discussed.

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The development of Aerospatiale's ATSF future supersonic transport is presented. Initial design methods call for a Mach 2 cruise level to permit constant verification between actual flight experience and new design concepts. Details of aerodynamics, structural design , materials available, and powerplant installation are discussed. Configuration development, cruise lift/drag improvement, structural layout, and cockpit design modifications are described. Engine selection considerations involving candidate engine cycles, engine installation and intake development are also described. The improvements being made in low speed performance and engine noise emission appear likely to achieve today's noise criteria by 2005.

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A review of the SST programs conducted by the United States, France, Great Britain and the USSR during the 1960s is presented. The designs that evolved considered such questions as the supersonic boom and other noise related problems that were directly related to environmental and public opinion issues. Development of the Concorde program is discussed, and a brief outline of the TU 144 project and the discontinued U.S. SST competition is presented. Some aspects of initial Concorde operational problems are also described.

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A new era of supersonic and hypersonic aviation is envisioned. The potential for supersonic and hypersonic flight vehicles in this new era is analyzed. Technology challenges that must be met in order to bring in this new era of flight are discussed. The current technical status and future potential are cited in the areas of aerodynamics, propulsion, and structural materials. A next major step in the development of high-speed air transportation is suggested.

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Studies relating to environmental factors associated with high speed civil transports were conducted. Projected total engine emissions for year 2015 fleets of several subsonic/supersonic transport fleet scenarios, discussion of sonic boom reduction methods, discussion of community noise level requirements, fuels considerations, and air traffic control impact are presented.

6. DOLLYHIGH, SAMUEL M.: **Technology issues for high-speed civil transports.** SAE PAPER 892201 SAE, Aerospace Technology Conference and Exposition, Anaheim, CA, Sept. 25-28, 1989. 11 p. 1989. 90A45422

Current efforts to prepare the technology for a new generation of high-speed civil transports are focused primarily on environmental issues.This paper reports on studies to provide: (1) acceptable engine emissions;(2) reduced airport/community noise; and (3) sonic-boom minimization. Attention is also given to technologies that allow a lighter, more efficient vehicle and to other high-payoff technologies, such as supersonic laminar flow; these have the potential for yielding not only better mission performance but also enhanced environmental compatibility for these new vehicles. The technology issues are reviewed in terms of the technologies themselves and their impact on the equally crucial need for economic success.

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The current development status of high-speed commercial transport aircraft is surveyed and analyzed by industry and government experts, with an emphasis on economic and policy implications. Sections are devoted to aircraft research and development, operations and markets, consortia and financing, and institutional considerations. Diagrams and graphs are provided, as well as an executive summary and summaries of the discussion at the symposium.

8. SPEARMAN, M. LEROY: **Before the high-speed civil transport**: AIAA PAPER 89-2081, AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Conference, Seattle, WA, July 31-Aug. 2, 1989. 8 p. 1989. 89A49445

Following the cancellation of the U.S. National SST Program in March, 1971, NASA conducted SST propulsion technology and configurational aerodynamics and structures development efforts through what came in the wake of a 1976 conference to be called the Supersonic Cruise Research and Variable Cycle Engine programs. These programs were in turn canceled in 1982. The present historical assessment of major advancements in passenger aircraft technology notes that the flying public has tended to be reluctant in accepting such innovations as swept-wing jet airliners and may be expected to be similarly wary about SST use.

9. HARRIS, ROY V., JR.: **On the threshold - The outlook for supersonic and hypersonic aircraft**. AIAA PAPER 89-2071 AIAA, AHS,and ASEE, Aircraft Design, Systems and Operations Conference, Seattle, WA,July 31-Aug. 2, 1989. 12 p. 89A49438

A development history and current development status evaluation is presented with a view to the prospective viability of supersonic, hypersonic, and transatmospheric vehicle R&D efforts. It is stressed that such high-speed vehicles will not supplant the current fleet of subsonic aircraft, but simply address the growing need for very long range commercial and military missions. Mach 2-3 airliners could be developed by the year 2000; Mach 5-6 military reconnaissance aircraft could be operational soon after. Transatmospheric, mixed air breathing/rocket propulsion single-stage vehicles capable of orbital insertion will require several years of additional development beyond hypersonic ones to become operational.

10. COONS, LEE: **Advanced materials for future high speed civil transport.** In NASA, Lewis Research Center, HITEMP Review 1989: Advanced High Temperature Engine Materials Technology Program. 1989. 90X10098 **DOMESTIC**

Major aerospace technological undertakings of the past continue to be built upon through planned future initiatives. With the emergence of other nations in the aerospace field, the United States must develop visionary initiatives that are both economically sound and environmentally acceptable if it is to retain its leadership; initiatives that not only bring new capabilities that maintain American leadership, but also provide economic growth for the United States. High payoff materials and structures required to meet the needs of an economically affordable and environmentally acceptable HSCT are being identified. A study aircraft was configured and a baseline engine was defined with current state-of-the-art materials and structures. Major advances in materials, structures, and aerodynamics were then incorporated into an advanced technology engine. A lower risk advanced technology engine was also studied to determine the impact of reducing operating temperatures. There are a number of challenges to be overcome to realize the potential of the HSCT. These challenges cover not only material development but also understanding of structural failure modes, design criteria, and development of affordable manufacturing processes. All of these challenges come with a price. Although the challenge is great, the payoff will allow the United States to maintain leadership in aerospace technology.

11. WELGE, H. ROBERT: **Aerodynamic technology opportunities for a high-speed civil transport.** SAE PAPER 881354 IN: Advanced aerospace aerodynamics; Proceedings of the Aerospace Technology Conference and Exposition, Anaheim, CA, Oct. 3-6, 1988 (89A51351 22-01). Warrendale,PA, Society of Automotive Engineers, Inc., 1988, p. 19-25. Research sponsored by McDonnell Douglas Corp. 1988. 89A51353

A NASA-sponsored study has undertaken the definition of SST and HST configurations resulting in substantial reductions relative to current technology in takeoff gross weight, sonic boom overpressures, and airport-vicinity propulsion and aerodynamic noise. CFD methods have been applied to vehicle-shaping and laminar boundary layer flow area-maximizing configurational studies. Various planforms and active boundary-layer control methods are considered. Computer-managed wing control surface deflections are identified as substantial contributors to wing aerodynamic load and structural weight reduction, while correcting undesirable aerodynamic-pitching characteristics.

12. GRAVES, RANDOLPH A., JR.: **Aerodynamics.** Exxon Air World, vol. 40, no. 2, 1988, p. 6-8. 1988. 88A53800

A projection is made of likely improvements in the economics of commercial aircraft operation due to developments in aerodynamics in the next half-century. Notable among these improvements are active laminar flow control techniques' application to third-generation SSTs, in order to achieve an L/D value of about 20; this is comparable to current subsonic transports, and has the further consequence of reducing cabin noise. Wave-cancellation systems may also be used to eliminate sonic boom overpressures, and rapid-combustion systems may be able to eliminate all pollutants from jet exhausts other than CO2.

13. STRACK, WILLIAM C.; MORRIS, SHELBY J., JR.: **The challenges and opportunities of supersonic transport propulsion technology AIAA PAPER 88-2985.** AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference and Exhibit, 24th, Boston, MA, July 11-13, 1988. 13 p. Previously announced in STAR as 88N23806. 1988. 88A48032

The major challenges confronting the propulsion community for civil supersonic transport applications are identified: high propulsion system efficiency at both supersonic and subsonic cruise conditions, low-cost fuel with adequate thermal stability at high temperatures, low noise cycles and exhaust systems, low emission combustion systems, and low drag installations. Both past progress and future opportunities are discussed in relation to perceived technology shortfalls for an economically successful airplane that satisfies environmental constraints.

14. MORRIS, CHARLES E. K., JR.; WINSTON, MATTHEW M.; MORRIS, SHELBY J., JR.: **Some key considerations for high-speed civil transports.** AIAA PAPER 88-4466 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Atlanta, GA, Sept. 7-9, 1988. 8 p. 1988. 88A53760

Factors affecting the development of a new generation of high-speed (supersonic/hypersonic) transports are reviewed. Market projections of growth on long-range routes indicate a potential need for faster transport aircraft by the turn of the century. A review of NASA-sponsored studies shows how both market forces and technology combine to define mission performance and vehicle design constraints. The vehicle worth and price projected for a given vehicle are shown to relate to an assumed technology level. Preliminary results from an initial set of vehicle concepts lead to the conclusion that currently projected technology will need to be enhanced with increased research to meet the first market window around the year 2000.

15. JACKSON, CHARLIE M., JR.; MORRIS, CHARLES E. K., JR.: **Unique research challenges for high-speed civil transports.** NASA-TM-100490 NAS 1.15:100490 1987. 87N27651

Market growth and technological advances are expected to lead to a generation of long-range transports that cruise at supersonic or even hypersonic speeds. Current NASA/industry studies will define the market windows in terms of time frame, Mach number, and technology requirements for these aircraft. Initial results indicate that, for the years 2000 to 2020, economically attractive vehicles could have a cruise speed up to Mach 6. The resulting research challenges are unique. They must be met with technologies that will produce commercially successful and environmentally compatible vehicles where none have existed. Several important areas of research were identified for the high-speed civil transports. Among these are sonic boom, takeoff noise, thermal management,lightweight structures with long life, unique propulsion concepts, unconventional fuels, and supersonic laminar flow.

16. LOOMIS, JAMES P.: **High speed commercial flight - The coming era**; Proceedings of the First Symposium, Columbus, OH, Oct. 22, 23, 1986 Symposium sponsored by the Battelle Memorial Institute, DOC, and Ohio Edison Program. Columbus, OH, Battelle Press, 1987, 286 p. No individual items are abstracted in this volume. 1987. 88A23258

The present consideration of the near- and long-term technological and economic feasibility of supersonic and hypersonic transport aircraft gives attention to the comparative attractiveness of intensified R&D for the supersonic and hypersonic regimes. It is noted that the technology readiness base for a Mach 3-cruise SST is inadequate, and that the U.S. National Aerospace Plane (NASP) program will do little or nothing to alleviate this shortfall. The technology readiness base for a Mach 5 commercial SST is also inadequate, and the NASP is anticipated to contribute to only 30 percent of these needs. The SST market in the foreseeable future will accommodate only one such economically viable aircraft.

17. DRIVER, C.: **How different a modern SST would be**. Aerospace America (ISSN 0740-722X), vol. 24, Nov. 1986, p. 26-29. 87A17143

The characteristics of a proposed SST are described. The proposed aircraft is to have two engines and an arrow-wing design, a passenger capacity of 250, and attain speeds of Mach 2.7. The low fineness ratio, low-aspect ratio wing planform, different engine nacelles location, and improved lift-to-drag ratio of the aircraft contribute to attaining an economical supersonic cruise. The proposed structural design and materials for the aircraft are examined; the material and design are to be applicable to high Mach and high temperature. Changes in the SST propulsion system, the nozzle designs, and landing and take off procedures to improve the operation of the aircraft are discussed.

18. WINBLADE, ROGER L.: **Supersonic cruise technology roadmap**. SAE PAPER 861685. SAE, Aerospace Technology Conference and Exposition, Long Beach, CA, Oct. 13-16, 1986. 9 p. 87A32601

One of the three National Aeronautical R&D Goals of the President's Office of Science and Technology Policy was the attainment of long-distance supersonic cruise capability. NASA was asked to lead the development of a 'technology roadmap' for this goal. The roadmap identified critical technology elements that need to be pursued and provided an outline of the most effective approach for achieving technology readiness. The effort, briefly addressed in this paper, was intended to provide a first top level framework to support the preparation of more detailed technical plans through the combined efforts of private and public sectors of the aeronautics community.

19. DRIVER, C.; MAGLIERI, D. J.: **The impact of emerging technologies on an advanced supersonic transport**. ICAS, Congress, 15th, London, England, September 7-12, 1986, Proceedings. Volume 1 (86A48976 24-01). New York, American Institute of Aeronautics and Astronautics, Inc., 1986, p. 213-220. 86A48997

The effects of advances in propulsion systems, structure and materials, aerodynamics, and systems on the design and development of supersonic transport aircraft are analyzed. Efficient propulsion systems with variable-cycle engines provide the basis for improved propulsion systems; the propulsion efficiencies of supersonic and subsonic engines are compared. Material advances consist of long-life damage-tolerant structures, advanced material development, aeroelastic tailoring, and low-cost fabrication. Improvements in the areas of aerodynamics and systems are examined. The environmental problems caused by engine emissions, airport noise, and sonic boom are studied. The characteristics of the aircraft designed to include these technical advances are described.

20. PETERSEN, R. H.; DRIVER, C.: **Readying technology for a super SST**. Aerospace America (ISSN 0740-722X), vol. 23, July 1985, p. 56-59. 85A41054

A technology readiness evaluation is made of the configurational, propulsion system, avionics, and materials/manufacturing methods which could be integrated to produce an economically viable SST by the year 2000. Aerodynamically, promising results are noted in the cases of arrow-wing planforms and blended wing/body cross sections, as well as in vortex flaps. In structures, metal matrix composites with high specific strength at high temperatures and thermoplastically formed/diffusion-bonded titanium alloy sandwich structures are identified as being of primary importance. Performance improvement prospects are also noted for engine efficiencies and sonic boom overpressures. The various technologies are envisaged as the bases for a two-engine, two-crew cockpit, 250-seat arrow-winged SST.

21. MCLEAN, F. EDWARD: **Supersonic cruise technology**. NASA-SP-472 NAS 1.21:472 LC-83-26912 1985. 85N28912

The history and status of supersonic cruise research is covered. The early research efforts of the National Advisory Committee for Aeronautics and efforts during the B-70 and SST phase are included. Technological progress made during the NASA Supersonic Cruise Research and Variable Cycle Engine programs are presented. While emphasis is on NASA's contributions to supersonic cruise research in the U.S., also noted are developments in England, France, and Russia. Written in nontechnical language, this book presents the most critical technology issues and research findings.

22. HOFFMAN, S.: **Supersonic cruise research.** NASA-TM-85465 NAS 1.15:85465 1983. 84X78916 NASA PERS. ONLY

23. EVELYN, G. B.; TJONNELAND, E.; GRANDE, D. L.: **Studies of advanced supersonic technologies.** NASA-CR-166076 NAS 1.26:166076D6-51156 1983. 83X10331 US GOV AGENCIES AND CONTRACTORS

Several propulsion and structural technology advancements that offered high potential for application to future supersonic transports were investigated. Propulsion: Inlet Flow Analysis: A 3-D boundary layer program and a 3-D shock/boundary layer interaction program were completed and combined with a method of characteristics program to yield a flow analysis procedure for a supersonic diffuser of an axisymmetric inlet at angle of attack. The analysis was applied to the P-inlet operating at angle of attack to illustrate the procedure. Inlet Controls: Modern technology was applied to the controls of a mixed compression inlet to develop an integrated airframe, inlet, engine simulation, and baseline inlet and engine controllers. The inlet control was implemented in a flight type, fault tolerant, triple channel controller. Nacelle Integration Analysis: Coupling of a nonlinearized potential flow solution embedded in a general solution of a larger domain using linearized potential flow was accomplished through a four step process and was applied through a preliminary analysis of a nacelle wing combination. NACA Nozzle Test: Analysis, design and laboratory testing was accomplished to verify predicted performance and secondary flow pumping capabilities of the Naturally Aspirated Co-annular (NACA) nozzle concept. Installed Nozzle Test Program: Test techniques and procedures for evaluating various nozzle concepts and installations were investigated as to their effect on airplane performance at transonic speeds and as a means of establishing configuration preliminary drag values.

24. DRIVER, C.: **Progress in supersonic cruise technology**. NATO, AGARD, Symposium/Workshop on Sustained Supersonic Cruise and Maneuver, Brussels, Belgium, Oct. 10-13, 1983, Paper. 11 p. 83A43025

The Supersonic Cruise Research (SCR) program identified significant improvements in the technology areas of aerodynamics, structures, propulsion, noise reduction, takeoff and landing procedures, and advanced configuration concepts. These improvements, when combined in a large supersonic cruise vehicle, offer a far greater technology advance than generally realized. They offer the promise of an advanced commercial family of aircraft which are environmentally acceptable, have flexible range-payload capability, and are economically viable. These same areas of technology have direct application to smaller advanced military aircraft and to supersonic executive aircraft. Several possible applications will be addressed.

25. **SST-follow-on program, phase 2.** 1983. 84N75696

26. **SST follow-on program, phase 2.** 1983. 84N75694

27. **SST follow-on program, phase 2.** 1983. 84N75693

28. SUSSMAN, M. B.; UPTON, G.; SEVIGNY, E.; PETIT, J. E.; SCHREFFLER, E. S.; STOECKLIN, R. L.; GOETZ, G. F.: **Study of potential for sustained supersonic cruise military aircraft utilizing advanced technologies, volume 1.** NASA-CR-165957 NAS 1.26:165957 D180-270781-1-VOL-1 1982. 82X10336 US GOV AGENCIES AND CONTRACTORS

Advanced technologies developed by NASA for commercial supersonic transport application were assessed for applicability to the military role. Two specific military missions were prescribed and aircraft configurations developed through parametric analysis and optimization. Key technologies were then evaluated in terms of vehicle gross weight impact. Research and development recommendations resulting from these analyses were formulated. Variable camber and vortex flap leading edges, advanced engine cycles propulsive lift, arrow wing/wing body blending, active controls, digital avionics, advanced structural materials, and thermal management are addressed.

29. ROWE, W. T.: **Technology status for an advanced supersonic transport.** SAE PAPER 820955 Society of Automotive Engineers, West Coast International Meeting, San Francisco, CA, Aug. 16-19, 1982. 9 p. 83A33627

An assessment is undertaken of the development status of a proprietary SST propulsion, structural design, materials, and aerodynamics research program. The Mach 2.2-cruise speed SST design considered incorporates a novel wing planform which results in a 45 percent lift-to-drag ratio improvement over the Concorde SST, and employs superplastic forming and diffusion bonding methods in the fabrication of a 78 percent Ti alloy structure. Composites are used in all secondary structures. A reoptimization of the engine cycle, which includes variable features, improves fuel efficiencies in the subsonic cruise regime. It is noted that jet noise suppression techniques are able to keep noise levels down to those of wide-bodied subsonic transports.

30. NAGEL, A. L.: **Aerodynamic research applications at Boeing.** International Council of the Aeronautical Sciences, Congress, 13th and AIAA Aircraft Systems and Technology Conference, Seattle, WA, August 22-27, 1982, Proceedings. Volume 2. (82A40876 20-01) New York, American Institute of Aeronautics and Astronautics, p. 1235-1242. 82A41000

This paper shows by several recent examples how aerodynamic research tools and methods have been applied to the design of subsonic commercial transport airplanes. Examples include wing modifications, nacelle integration, vortex generators, and cab design. Some recent high Reynolds number tests in the NASA 0.3-meter Transonic Cryogenic Tunnel are also described.

31. BRUCKMAN, F. A.; CLAUSS, J. S., JR.; BANGERT, L. H.; SAKATA, I. F.; GODBY, L.; SARAMES, G. N.: **Integrated technology studies for advanced supersonic cruise vehicles.** NASA-CR-165819 LR-30074 1981. 82X10034 US GOV AGENCIES AND CONTRACTORS

A compilation of engineering analysis and testing of integrated technology studies for advanced supersonic cruise vehicles (SCV) is provided. A systems study involving selective in-depth design, analysis, and testing of significant aircraft components for possible future commercial transport was made. The major technical areas studied were: propulsion/airframe integration, subsonic flight noise attenuation, advanced aluminum alloy powder metallurgy, advanced hybrid structural concepts, and economic viability of the supersonic cruise vehicle. Potential markets for supersonic transports are identified giving considerations to aircraft range, route restrictions, and subsonic traffic that is divertible to SCV aircraft.

32. DOLLYHIGH, S. M.; FOSS, W. E., JR.; MORRIS, S. J., JR.; ALFORD, W. J., JR.: **Potential flight efficiency of advanced supersonic configurations.** 1981. 81X10191 US GOV AGENCIES AND CONTRACTORS

The flight efficiency characteristics of the Supersonic Cruise Integrated Fighter configurations are analyzed. It is concluded that it is possible to develop efficiencies of sufficient magnitude to make feasible sustained supersonic cruise missions. These supersonic efficiencies are two to five times higher than existing aircraft, without significant reductions in subsonic efficiencies, and with reasonable maneuver capability. The characteristics of some current aircraft capable of supersonic flight, including advanced supersonic transports, are presented for comparison.

33. ROWE, W. T.: **Technology study for advanced supersonic cruise vehicles.** NASA-CR-165723 MDC-J4668 1981. 81X10344 US GOV AGENCIES AND CONTRACTORS

Technologies and research programs were evaluated for development of a solid technology base from which an advanced supersonic cruise aircraft can be derived. Propulsion technology and structural technology studies result in a range improvement of 5 percent for the Mach 2.2 baseline aircraft. Configuration studies to increase the passenger capacity to 350 at maximum takeoff gross weight of 340,200 kg are complete. Test of an improved supersonic cruise vehicle wing verify that current analytical performance estimating methods are accurate. Structural analysis of applications of SPF/DB titanium sandwich in detail design sows substantial payoff in weight and cost of fabrication. Propulsion integration studies update the technology for the variable cycle engines and suppression schemes to a 1984 go-ahead date. The improved performance data are summarized for six different engines.

34. HUNT, R. B.: **Noise and economic study for supersonic cruise airplane research.** NASA-CR-165423 PWA-5701-22 1981. 81X10332 US GOV AGENCIES AND CONTRACTORS

Analytical comparisons of engine/airplane direct operating cost versus traded noise were generated for three study

engines based on the National Aeronautics and Space Administration Advanced Supersonic Transport (AST)-105-1 airplane concept adjusted to a design range of 7408 km (4000 naut mi). The three study engines evaluated were the low bypass engine, variable stream control engine, and inverted flow engine. The economic comparisons were evaluated on a 5926 km (3200 naut mi) mission with a 556 km (300 naut mi) subsonic leg, which was chosen as being representative of North Atlantic service.

35. DRIVER, C.: **Progress in supersonic cruise technology**. AIAA PAPER 81-1687 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Conference, Dayton, OH, Aug.11-13, 1981, 11 p. 81A43950

It is reported that nine years of NASA research have yielded significant design solutions in such matters pertaining to large supersonic cruise vehicles as aerodynamics, structures, propulsion, noise reduction, take off and landing procedures, and advanced configuration concepts. Attention is given to the incremental performance gains achieved over the years (with the Concorde SST as baseline reference), arrow wing planform performance potential, superplastic forming/diffusion bonding of titanium alloy primary structures, advanced engine cycles, twin-fuselage high-capacity configurations, and the potential military payoff of SST research. It is concluded that the greatest promise for future research and development lies in fiber-reinforced, high-temperature metal structures and the twin-fuselage configuration.

36. ROWE, W. T.; WELGE, H. R.; JOHNSON, E. S.; ROCHTE, L. S.: **Advanced supersonic transport propulsion and configuration technology improvements**. AIAA PAPER 81-1595 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 13 p. 81A40970

This paper presents the results of recent Douglas Aircraft Company integration studies for an advanced supersonic transport. The studies include technology improvements such as superplastic formed and diffusion-bonded titanium sandwich primary structure, composite secondary structure, bicone engine inlet, improved mechanical suppressors based on flight test data, improved aerodynamic efficiency based on wind tunnel test data, and updated performance for both variable-cycle and low-bypass-ratio engines. Technology development requirements for an economically viable and environmentally acceptable advanced supersonic transport are defined through these studies. A new Douglas Aircraft Company baseline supersonic transport designed to carry 350 passengers is defined for cost comparisons.

37. MAXWELL, R. L.; DICKINSON, L. V., JR.: **Assessment of the impact of advanced air-transport technology**. In NASA, Langley Research Center Supersonic Cruise Research, 1979, Pt. 2, p805-819, (See 81N18005 09-01) 1981. 81N18015

The long term prospects for commercial supersonic transportation appear attractive enough to keep supersonic research active and reasonably healthy. On the other hand, the uncertainties surrounding an advanced supersonic transport (AST), specifically fuel price, fuel availability and noise, are too significant to warrant an accelerated research and development program until they are better resolved. It is estimated that an AST could capture about $50 billion (1979 dollars) of the potential $150 billion in sales up to the year 2010.

38. Supersonic Cruise Research 1979, part 1. NASA-CP-2108-PT-1 L-13385-PT-1. 1980. 81N17981

39. Supersonic Cruise Research 1979, part 2. NASA-CP-2108-PT-2 L-13385-PT-2. 1980. 81N18005

40. ROWE, W. T.: **Technology development status at McDonnell Douglas**. In NASA, Langley Research Center Supersonic Cruise Research, 1979, Pt. 2, p 873-888 (See 81N18005 09-01) 1981. 81N18019

The significant technology items of the Concorde and the conceptual MCD baseline advanced supersonic transport are compared. The four major improvements are in the areas of range performance, structures (materials), aerodynamics, and in community noise. Presentation charts show aerodynamic efficiency; the reoptimized wing; low scale lift/drag ratio; control systems; structural modeling and analysis; weight and cost comparisons for super- plasticity diffusion bonded titanium sandwich structures and for aluminum brazed titanium honeycomb structures; operating cost reduction; suppressor nozzles; noise reduction and range; the bicone inlet; a market summary; environmental issues; high priority items; the titanium wing and fuselage test components; and technology validation.

41. ROWE, W. T.: **Technology study for advanced supersonic cruise vehicles.** NASA-CR-165723 MDC-J4668 1981. 81X10344 US GOV AGENCIES AND CONTRACTORS

Technologies and research programs were evaluated for development of a solid technology base from which an advanced supersonic cruise aircraft can be derived. Propulsion technology and structural technology studies result in a range improvement of 5 percent for the Mach 2.2 baseline aircraft. Configuration studies to increase the passenger capacity to 350 at maximum takeoff gross weight of 340,200 kg are complete. Test of an improved supersonic cruise vehicle wing verify that current analytical performance estimating methods are accurate. Structural analysis of applications of SPDB titanium sandwich in detail design sows substantial payoff in weight and cost of fabrication. Propulsion integration studies update the technology for the variable cycle engines and suppression schemes to a 1984 go-ahead date. The improved performance data are summarized for six different engines.

42. SIGALLA, A.: **Overview of Boeing supersonic transport efforts, 1971 - 1979.** In NASA, Langley Research Center Supersonic Cruise Research, 1979, Pt. 2, p821-832 (See 81N18005) 1980. 81N18016

Following cancellation of the United States Supersonic Transport program, the status of the technology was assessed carefully and emphasis was put on finding solutions for what were considered the major technical difficulties. In particular, work on the breakthroughs needed to advance the technology was emphasized. Currently, solutions to all major technical problems are identified. Depending on the subject, either the problem is no longer a concern or the steps needed to bring about a solution are mapped out clearly. Throughout the NASA SCR program, important strides were made in the identification of design advances which would greatly improve supersonic airplane fuel efficiency, noise, and other performance and cost affecting parameters. Furthermore, these efforts created an atmosphere in which it was possible for new ideas to flourish and positive inventions to take place such as the variable cycle engine and the blended fuselage. These technical gains show that, given availability of such technology, advanced supersonic transports could be developed that would be economically successful and environmentally acceptable.

43. Technology study for advanced supersonic cruise vehicles. NASA-CR-185898 NAS 1.26:185898 1980. 90X70651 US GOV AGENCIES AND CONTRACTORS

44. Technology application study of a supersonic cruise vehicle. NASA-CR-159034 MDC-J4624 1979. 79X10160 US GOV AGENCIES AND CONTRACTORS

A Mach 2.2 baseline configuration was defined for application of advanced technologies in the development of an advanced supersonic cruise aircraft. Aerodynamics, active control systems, structures, propulsion, inlet/airframe integration, and configuration integration refinements were emphasized. Results of analyses in these areas are presented and discussed.

45. SWEETMAN, B.: **The next supersonic transport.** Flight International, vol. 116, Nov. 24, 1979, p. 1772-1774, 1779. 80A20214

The article investigates future concepts for supersonic transports, noting that the concept is still viable because the efficiency of air travel is related to speed. In theory, the less time an aircraft has to be airborne, the less energy it will use, so faster aircraft should be more efficient. Discussion covers such areas as compromises in wing construction for take off and landing and supersonic cruise, and comparisons between delta and arrow wings. Similar problems in engine design are also considered such as the conflict between noise and supersonic performance. Weight factors are also investigated as regards the use of composites, as well as the use of hydrogen as a fuel. Finally, it is noted that the general consensus is that a future SST should be substantially larger than the Concorde (about 230 passengers) and have a non-stop Pacific range.

46. Technology application study of a supersonic cruise vehicle. NASA-CR-162920 MDC-J4578 1977. 80N72822

47. Technology application study of an advanced supersonic cruise vehicle, phases. Advanced supersonic propulsion studies. NASA-CR-159315 PWA-5536-8 1977. 80X10118 US GOV AGENCIES AND CONTRACTORS

Pratt & Whitney Aircraft conducted a nine-month program for the McDonnell Douglas Corporation to study

advanced-technology propulsion systems for a supersonic cruise aircraft conceptually defined by Douglas. This program is part of an overall effort to eventually establish a viable technology base for advanced supersonic aircraft systems. The scope of work consisted of conducting propulsion system analyses and engine aircraft integration analyses with two engine concepts, a Low Bypass Engine (LBE) and a Variable Stream Control Engine (VSCE). The main conclusion derived is that both engine concepts are fully compatible with the Douglas supersonic cruise vehicle. The VSCE-55D study engine, with its unique variable throttle schedule, is the most promising engine concept on the basis of weight, overall performance and coannular noise benefits. The LBE-431 study engine is the preferred alternate engine definition.

48. **Proceedings of the SCAR Conference, part 2.** NASA-CP-001-PT- 1976. 77N18019

49. **Proceedings of the SCAR Conference, part 1.** NASA-CP-001-PT- 1976. 77N17996

50. **SST follow-on program, phase 2.** 1975. 84N75690

51. **SST follow-on program, phase 2.** 1975. 84N75689

52. SMITH, C. L.; WILLIAMS, L. J.: **An economic study of an advanced technology supersonic cruise vehicle.** NASA-TM-X-62499 A-6333 1975. 76N10996

A description is given of the methods used and the results of an economic study of an advanced technology supersonic cruise vehicle. This vehicle was designed for a maximum range of 4000 n.mi. at a cruise speed of Mach 2.7 and carrying 292 passengers. The economic study includes the estimation of aircraft unit cost, operating cost, and idealized cash flow and discounted cash flow return on investment. In addition, it includes a sensitivity study on the effects of unit cost, manufacturing cost, production quantity, average trip length, fuel cost, load factor, and fare on the aircraft's economic feasibility.

53. KULFAN, R. M.: **High-transonic-speed transport aircraft study**. NASA-CR-2465 D6-60231 1974. 74N31505

An initial design study of high-transonic-speed transport aircraft has been completed. Five different design concepts were developed. These included fixed swept wing, variable-sweep wing, delta wing, double-fuselage yawed-wing, and single-fuselage yawed-wing aircraft. The boomless supersonic design objectives of range = 5560 km (3000 nmi), payload = 18,143 kg (40,000 lb), Mach = 1.2, and FAR Part 36 aircraft noise levels were achieved by the single-fuselage yawed-wing configuration with a gross weight of 211,828 kg (467,000 lb). A noise level of 15 EPNdB below FAR Part 36 requirements was obtained with a gross weight increase to 226,796 kg (500,000 lb). The off-design subsonic range capability for this configuration exceeded the Mach 1.2 design range by more than 20%. Although wing aeroelastic divergence was a primary design consideration for the yawed-wing concepts, the graphite-epoxy wings of this study were designed by critical gust and maneuver loads rather than by divergence requirements. The transonic nacelle drag is shown to be very sensitive to the nacelle installation. A six-degree-of-freedom dynamic stability analysis indicated that the control coordination and stability augmentation system would require more development than for a symmetrical airplane but is entirely feasible. A three-plane development plan is recommended to establish the full potential of the yawed-wing concept.

54. KULFAN, R. M.; NISBET, J. W.; NEUMAN, F. D.; HAMILTON, E. J.; MURAKAMI, J. K.; MCBARRON, J. P.; KUMASAKA, K.: **Study of the single body yawed-wing aircraft concept**. NASA-CR-13748 1974. 74N27485

Areas relating to the development and improvement of the single-fuselage, yawed-wing transonic transport concept were investigated. These included: (1) developing an alternate configuration with a simplified engine installation;(2) determining a structural design speed placard that would allow the engine-airframe match for optimum airplane performance; and (3) conducting an aeroelastic stability and control analysis of the yawed-wing configuration with a flexible wing. A two-engine, single-fuselage, yawed-wing configuration was developed that achieved the Mach 1.2 design mission at 5560 km (3000 nmi) and payload of 18,140 kg (40,000 lb) with a gross weight of 217,700 kg (480,000 lb). This airplane was slightly heavier than the aft-integrated four-engine configuration that had been developed in a previous study. A modified structural design speed placard, which was determined, resulted in a 6% to 8% reduction in the gross weight of the yawed-wing configurations. The dynamic stability characteristics of the single-fuselage yawed-wing configuration were found to be very dependent on the magnitude of the pitch/roll coupling, the static longitudinal stability, and the dihedral effect.

55. KULFAN, R. M.; NEUMANN, F. D.; NISBET, J. W.; MULALLY, A. R.; MURAKAMI, J. K.; NOBLE, E. C.; MCBARRON, J. P.; STALTER, J. L.; GIMMESTAD, D. W.; SUSSMAN, M. B.: **High transonic speed transport aircraft study.** NASA-CR-114658 1973. 74N17750

An initial design study of high-transonic-speed transport aircraft has been completed. Five different design concepts were developed. These included fixed swept wing, variable-sweep wing, delta wing, double-fuselage yawed-wing, and single-fuselage yawed-wing aircraft. The boomless supersonic design objectives of range=5560 Km (3000 nmi), payload-18 143 kg (40 000lb), Mach=1.2, and FAR Part 36 aircraft noise levels were achieved by the single-fuselage yawed-wing configuration with a gross weight of 211 828 Kg (467 000 lb). A noise level of 15 EPNdB below FAR Part 36 requirements was obtained with a gross weight increase to 226 796 Kg (500 000 lb). Although wing aeroelastic divergence was a primary design consideration for the yawed-wing concepts, the graphite-epoxy wings of this study were designed by critical gust and maneuver loads rather than by divergence requirements. The transonic nacelle drag is shown to be very sensitive to the nacelle installation. A six-degree-of-freedom dynamic stability analysis indicated that the control coordination and stability augmentation system would require more development than for a symmetrical airplane but is entirely feasible. A three-phase development plan is recommended to establish the full potential of the yawed-wing concept.

56. SST follow-on program, phase 2. 1974. 84N75692

57. SST follow-on program, phase 2. 1974. 84N75691

58. COSLEY, D. H.; DALE, H. E.: **SST Technology Follow-On Program, phase 2: ADEDS flight test report. Volume 1: Flight test plan.** AD-920807 D6-60299-1 FAA-SS-73-22-1 1974. 88N70572 US GOV AGENCIES ONLY

59. WRIGHT, P.; PEAL, R.: **SST Technology Follow-On Program, phase 2: ADEDS flight test report. Volume 2: Airplane installation.** AD-920808 D6-60299-2 FAA-SS-73-22-2 1974. 88N70573 US GOV AGENCIES ONLY

60. Studies of the impact of advanced technologies applied to supersonic transport aircraft. Task 1 oral review. NASA-CR-145051-1 NAS 1.26:145051-1 LR-25582 1972. 84X71502 US GOV AGENCIES AND CONTRACTORS

1.2 CONCEPTUAL DESIGNS

61. Advanced supersonic transport systems study.: NASA-CR-185872 NAS 1.26:185872 MDC-J4379 1973. 90N70196

62. Study of high-speed civil transports. Summary. NASA-CR-4236 NAS 1.26:4236 1990. 90N25966

A systems study to identify the economic potential for a high-speed commercial transport has considered technology, market characteristics, airport infrastructure, and environmental issues. Market forecasts indicate a need for high speed civil transport (HSCT) service in the 2000/2010 time frame conditioned on economic viability and environmental acceptability. Design requirements focused on a 300 passenger, 3 class service, and 6500 nautical mile range based on the accelerated growth of the Pacific region. Compatibility with existing airports was an assumed requirement. Mach numbers between 2 and 25 were examined in conjunction with the appropriate propulsion systems, fuels, structural materials, and thermal management systems. Aircraft productivity was a key parameter with aircraft worth, in comparison to aircraft price, being the airline-oriented figure of merit. Aircraft screening led to determination that Mach 3.2 (TSJF) would have superior characteristics to Mach 5.0 (LNG)and the recommendation that the next generation high-speed commercial transport aircraft use a kerosene fuel. The sensitivity of aircraft performance and economics to environmental constraints (e.g., sonic boom, engine emissions, and airport/community noise) was identified together with key technologies. In all, current technology is not adequate to produce viable HSCTs for the world marketplace. Specific technology requirements have been identified which was the prime objective of this study. National economic benefits are projected.

63. BOGARDUS, SCOTT; LOPER, BRENT; NAUMAN, CHRIS; PAGE, JEFF;PARRIS, RUSTY; STEINBACH, GREG: **High speed civil transport.** NASA-CR-186661 NAS 1.26:186661 1990. 90N23396

The design process of the High Speed Civil Transport (HSCT) combines existing technology with the expectation of future technology to create a Mach 3.0 transport. The

HSCT was designed to have a range in excess of 6000 nautical miles and carry up to 300 passengers. This range will allow the HSCT to service the economically expanding Pacific Basin region. Effort was made in the design to enable the aircraft to use conventional airports with standard 12,000 foot runways. With a takeoff thrust of 250,000 pounds, the four supersonic through-flow engines will accelerate the HSCT to a cruise speed of Mach 3.0. The 679,000 pound (at takeoff) HSCT is designed to cruise at an altitude of 70,000 feet, flying above most atmospheric disturbances.

64. DOMACK, CHRISTOPHER S.; DOLLYHIGH, SAMUEL M.; BEISSNER, FREDL., JR.; GEISELHART, KARL A.; MCGRAW, MARVIN E., JR.; SHIELDS, ELWOOD W.; SWANSON, EDWARD E.: **Concept development of a Mach 4.0 high-speed civil transport.** NASA-TM-4223 L-16603 NAS 1.15:4223 1990. 90X36120 NASA PERS. ONLY

A study conducted to configure and analyze a 250-passenger, Mach 4 High Speed Civil Transport with a design range of 6500 n.mi. The design mission assumed and all-supersonic cruise segment and no community noise or sonic boom constraints. The study airplane was developed in order to examine the technology requirements for such a vehicle and to provide an unconstrained baseline from which to assess changes in technology levels, sonic boom limits, or community noise constraints in future studies. The propulsion, structure, and materials technologies utilized in the sizing of the study aircraft were assumed to represent a technology availability date of 2015.The study airplane was a derivative of a previously developed Mach 3 concept and utilized advanced afterburning turbojet engines and passive airframe thermal protection. Details of the configuration development, aerodynamic design, propulsion system, mass properties, and mission performance are represented. The study airplane was estimated to weigh approx. 866,000 pounds. Although an aircraft of this size is a marginally acceptable candidate to fit into the world airport infrastructure, it was concluded that the inclusion of community noise or sonic boom constraints would quickly cause the aircraft to grow beyond acceptable limits using the technology levels assumed in the study.

65. Study of high-speed civil transports. NASA-CR-4235 NAS 1.26:4235 1989. 90N13370

A systems study to identify the economic potential for a high-speed commercial transport (HSCT) has considered technology, market characteristics, airport infrastructure, and environmental issues. Market forecasts indicate a need for HSCT service in the 2000/2010 time frame conditioned on economic viability and environmental acceptability. Design requirements focused on a 300 passenger, 3 class service, and 6500 nautical mile range based on the accelerated growth of the Pacific region. Compatibility with existing airports was an assumed requirement. Mach numbers between 2 and 25 were examined in conjunction with the appropriate propulsion systems, fuels, structural materials, and thermal management systems. Aircraft productivity was a key parameter with aircraft worth, in comparison to aircraft price, being the airline-oriented figure of merit. Aircraft screening led to determination that Mach 3.2 (TSJF) would have superior characteristics to Mach 5.0 (LNG) and the recommendation that the next generation high-speed commercial transport aircraft use a kerosene fuel. The sensitivity of aircraft performance and economics to environmental constraints (e.g., sonic boom, engine emissions, and airport/community noise) was identified together with key technologies. In all, current technology is not adequate to produce viable HSCTs for the world marketplace. Technology advancements must be accomplished to meet environmental requirements (these requirements are as yet undetermined for sonic boom and engine emissions). High priority is assigned to aircraft gross weight reduction which benefits both economics and environmental aspects. Specific technology requirements are identified and national economic benefits are projected.

66. High-speed civil transport study. NASA-CR-4233 NAS 1.26:4233 1989. 89N27648

A system study of the potential for a high-speed commercial transport has addressed technological, economic, and environmental constraints. Market projections indicate a need for fleets of transports with supersonic or greater cruise speeds by the year 2000 to 2005. The associated design requirements called for a vehicle to carry 250 to 300 passengers over a range of 5,000 to 6,000 nautical miles. The study was initially unconstrained in terms of vehicle characteristic, such as cruise speed, propulsion systems, fuels, or structural materials. Analyses led to a focus on the most promising vehicle concepts. These were concepts that used a kerosene-type fuel and cruised at Mach numbers between 2.0 to 3.2. Further systems study identified the impact of environmental constraints (for community noise, sonic boom, and engine emissions) on economic attractiveness and technological needs. Results showed that current technology cannot produce a viable high-speed civil transport; significant advances are required to reduce takeoff gross weight and allow for both economic

attractiveness and environmental acceptability. Specific technological requirements were identified to meet these needs.

67. High-speed civil transport study. Summary. NASA-CR-4234 NAS 1.26:4234 1989. 89N27647

A system of study of the potential for a high speed commercial transport aircraft addressed technology, economic, and environmental constraints. Market projections indicated a need for fleets of transport with supersonic or greater cruise speeds by the years 2000 to 2005. The associated design requirements called for a vehicle to carry 250 to 300 passengers over a range of 5000 to 6000 nautical miles. The study was initially unconstrained in terms of vehicle characteristics, such as cruise speed, propulsion systems, fuels, or structural materials. Analyses led to a focus on the most promising vehicle concepts. These were concepts that used a kerosene type fuel and cruised at Mach numbers between 2.0 to 3.2. Further systems study identified the impact of environmental constraints (for community noise, sonic boom, and engine emissions) on economic attractiveness and technological needs. Results showed that current technology cannot produce a viable high speed civil transport. Significant advances are needed to take off gross weight and allow for both economic attractiveness and environment acceptability. Specific technological requirements were identified to meet these needs.

68. PITTMAN, JAMES L.; BONHAUS, DARYL L.; DOLLYHIGH, SAMUEL M.; SICLARI, MICHAEL J.: **An Euler analysis of a High-Speed Civil Transport (HSCT) concept at Mach 3.** AIAA PAPER 89-2174 AIAA, Applied Aerodynamics Conference, 7th, Seattle, WA, July 31-Aug. 2, 1989. 9p. 1989. 89A49680

A marching Euler solver, GEM3D, was used to predict the Mach 3 flow field for the wing and body of a High-Speed Civil Transport concept. The analysis focused on a typical cruise lift coefficient of 0.1 at alpha = 3 deg. The Euler solution indicated that embedded shocks formed on the upper surface of the inboard wing panel and at the leading-edge of the outboard wing panel, due to its supersonic leading edge condition. According to a simple static-pressure criterion, the embedded wing upper-surface shocks were sufficiently strong to separate a turbulent boundary layer. Comparison of aerodynamic coefficients from the Euler solver with those from linear theory shows that the linear theory estimates of lift and drag are optimistic, which would lead to optimistic estimates of cruise range.

69. VANDERVELDEN, ALEXANDER J. M.: **The conceptual design of a Mach 2 Oblique Flying Wing supersonic transport.** NASA-CR-177529 NAS1.26:177529 1989. 89N25233

This paper is based on a performance and economics study of a Mach two oblique flying wing transport aircraft that is to replace the B747B. In order to fairly compare our configuration with the B747B an equal structural technology level is assumed. It will be shown that the oblique flying wing configuration will equal or outperform the B747 in speed, economy and comfort while a modern stability and control system will balance the aircraft and smooth out gusts. The aircraft is designed to comply with the FAR25 airworthiness requirements and FAR36 stage 3 noise regulations. Geometry, aerodynamics, stability and control parameters of the oblique flying wing transport are discussed.

70. HITTMAN, JAMES L.; BONHAUS, DARYL L.; DOLLYHIGH, SAMUEL M.; SICLARI, MICHAEL J.: **An Euler analysis of a High-Speed Civil Transport (HSCT) concept at Mach 3.** AIAA PAPER 89-2174 AIAA, Applied Aerodynamics Conference, 7th, Seattle, WA, July 31-Aug. 2, 1989. 9 p. 89A49680

A marching Euler solver, GEM3D, was used to predict the Mach 3 flow field for the wing and body of a High-Speed Civil Transport concept. The analysis focused on a typical cruise lift coefficient of 0.1 at alpha = 3 deg. The Euler solution indicated that embedded shocks formed on the upper surface of the inboard wing panel and at the leading-edge of the outboard wing panel, due to its supersonic leading edge condition. According to a simple static-pressure criterion, the embedded wing upper-surface shocks were sufficiently strong to separate a turbulent boundary layer. Comparisons were done of aerodynamic coefficients from the Euler solver with those from linear theory.

71. TORENBEEK, EGBERT; VAN DER VELDEN, ALEXANDER J. M.: **Design of a small supersonic oblique-wing transport aircraft.** Journal of Aircraft (ISSN 0021-8669), vol. 26, March 1989, p. 193-197. 89A29160

Previous work in the early 1970s has shown the merits of a (large) transonic oblique-wing transport. In this paper, the suitability of the oblique-wing planform for a small supersonic transport aircraft will be shown. The aircraft is designed to transport 24 passengers with first-class accommodations at a cruising speed of 1500 km/h over a distance of 5800 km. It complies to the JAR 25 and FAR

25 airworthiness requirements and the FAR 36 stage 3 noise regulations and is powered by two medium bypass turbofan engines. The proposed aircraft offers a typical increase in blockspeed of 53 percent at ranges of 4000-7000 km compared with similar small transport aircraft, with comparable fuel efficiency, range, and field performances.

72. NIEDZWIECKI, R. W.: **High speed civil transport study**. 1988. 90X72489 DOMESTIC

73. MARTIN, GLENN L.; BEISSNER, FRED L., JR.; DOMACK, CHRISTOPHER S.; SHIELDS, E. WILLIAM: **The influence of subsonic mission segments on the use of variable-sweep wings for high speed civil transport configurations.** AIAA PAPER 88-4470 AIAA, AHS, and ASEE,Aircraft Design, Systems and Operations Meeting, Atlanta, GA, Sept. 7-9, 1988. 9 p. 1988. 88A51962

A Mach-3.0, 250-passenger, 6500-n. mi. range SST configuration's alternative use of fixed-planform or variable-sweep wings is presently evaluated, with a view to effects on aerodynamics, mission performance, and sizing. After preliminary design, the fixed and variable-wing configurations were resized to perform missions incorporating subsonic cruise segments of as much as 4000 n. mi.; the effect of subsonic segment length on design gross weight and block time was then ascertained. Due to the reduced supersonic efficiency of the variable-sweep aircraft, over one-half of the 6500-n. mi. mission would have to be flown subsonically for its sizing to reach a lower ramp weight than that of its fixed-geometry counterpart.

74. HENDRICH, LOUIS J.: **Preliminary design of two transpacific high speed civil transports.** AIAA PAPER 88-4485B AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Atlanta, GA, Sept. 7-9, 1988. 8 p. Research supported by Universities Space Research Association. 1988. 88A53765

Two high speed civil transport design concepts are presented. Both transports are designed for a 5500 n.m. range with 300 passengers. The first design concept is a Mach 2.5 joined-wing single fuselage transport. The second design concept is a Mach 4.0, twin fuselage, variable sweep wing transport. The use of conventional hydrocarbon fuels is emphasized to reduce the amount of change required in current airport facilities. Advanced aluminum alloys are used in the designs when possible to reduce material and production costs over more 'exotic' materials. Methods to reduce the airport noise, community noise, and fly-over noise are incorporated into the designs. In addition, requirements set forth by the FARs have been addressed.

75. CASS, S. H.; BALL, C. M.: **Planform effects on high speed civil transport design.** AIAA PAPER 88-4487 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Atlanta, GA, Sept. 7-9, 1988. 13 p. 1988. 88A53767

A Universities Space Research Association (USRA) sponsored (undergraduate) study is presented on planform effects on high speed civil transport design in the Mach 3 to 6 range. A request for proposal and mission profile was common to four aircraft designs. These air-craft were designed to the same mission in order to draw conclusions regarding the performance of the aircraft. The four configurations considered were the blended-wing-body concept, joined wing concept, oblique wing concept and the caret (waverider) concept. This paper presents the overall trends common to the four configurations during high speed flight. Conclusions on the best planform are left to the reader due to the fact that the designs all have positive and negative aspects. However, the paper points out these positive and negative aspects for each area of the design.

76. ROBINS, A. WARNER; DOLLYHIGH, SAMUEL M.; BEISSNER, FRED L., JR.; GEISELHART, KARL; MARTIN, GLENN L.; SHIELDS, E. W.; SWANSON, E. E.; COEN, PETER G.; MORRIS, SHELBY J., JR.: **Concept development of a Mach 3.0 high-speed civil transport**. NASA-TM-4058 L-16445 NAS 1.15:4058 1988. 88N27182

A baseline concept for a Mach 3.0 high-speed civil transport concept was developed as part of a national program with the goal that concepts and technologies be developed which will enable an effective long-range high-speed civil transport system. The Mach 3.0 concept reported represents an aggressive application of advanced technology to achieve the design goals. The level of technology is generally considered to be that which could have a demonstrated availability date of 1995 to 2000. The results indicate that aircraft are technically feasible that could carry 250 passengers at Mach 3.0 cruise for a 6500 nautical mile range at a size, weight and performance level that allows it to fit into the existing world airport structure. The details of the configuration development, aerodynamic design, propulsion system design and integration, mass properties, mission performance, and sizing are presented.

77. HENDRICH, LOUIS J.: **Results of a preliminary study of two high-speed civil transport design concepts.** International Conference on Hypersonic Flight in the 21st Century, 1st, Grand Forks, ND, Sept. 20-23, 1988, Proceedings (89A54326 24-15). Grand Forks, ND, University of North Dakota, 1988, p. 469-475. Research supported by the Universities Space Research Association. 89A54372

Two high speed civil transport (HSCT) design concepts are presented. Both transports are designed for 5500 n.m. range with 300 passengers. The first design concept is a Mach 2.5 joined-wing single fuselage transport. The second design concept is a Mach 4.0, twin fuselage, variable sweep wing transport. The use of conventional hydrocarbon fuels is emphasized to reduce the amount of change required in current airport facilities. Advanced aluminums are used in the designs when possible to reduce material and production costs over more 'exotic' materials. Methods to reduce the airport noise, community noise, and fly-over noise are incorporated into the designs. In addition, requirements set forth by the Federal Aviation Regulations (FAR's) have been addressed.

78. MARTIN, GLENN L.; BEISSNER, FRED L., JR.; DOMACK, CHRISTOPHER S.; SHIELDS, E. WILLIAM: **The influence of subsonic mission segments on the use of variable-sweep wings for high speed civil transport configurations.** AIAA PAPER 88-4470 AIAA, AHS, and ASEE,Aircraft Design, Systems and Operations Meeting, Atlanta, GA, Sept. 7-9, 1988. 9 p. 88A51962

A Mach-3.0, 250-passenger, 6500-n. mi. range SST configuration's alternative use of fixed-planform or variable-sweep wings is presently evaluated, with a view to effects on aerodynamics, mission performance, and sizing. After preliminary design, the fixed and variable-wing configurations were resized to perform missions incorporating subsonic cruise segments of as much as 4000 n. mi.; the effect of subsonic segment length on design gross weight and block time was then ascertained. Due to the reduced supersonic efficiency of the variable-sweep aircraft, over one-half of the 6500-n. mi. mission would have to be flown subsonically for its sizing to reach a lower ramp weight than that of its fixed-geometry counterpart.

79. GALL, P. D.: **Study of an efficient long-range Mach 2.7 supersonic transport configuration concept.** NASA-TM-86414 NAS 1.15:86414 1985. 85N32110

A long range Mach 2.7 supersonic transport configuration concept was studied utilizing linear theory methods. The configuration was sized to carry 290 passengers 6,000 nautical miles nonstop. The final configuration has a maximum takeoff gross weight of 687,200 pounds, a wing loading of 69.8 lbf/sq.ft. and a thrust weight ratio of .278. The most significant result is that a significantly improved trimmed maximum lift drag ratio of 11.04 can be obtained for a supersonic transport at Mach 2.62 and 55,000 feet.

80. TOCAPONE, F. J.; BARE, E. A.; HOLLENBACK, D.; HUTCHISON, R.: **Subsonic/supersonic aerodynamic characteristics for a tactical supercruiser.** AIAA PAPER 84-2192 American Institute of Aeronautics and Astronautics, Applied Aerodynamics Conference, 2nd, Seattle, WA, Aug. 21-23, 1984. 17 p. 84A44195

A series of cooperative NASA-Langley/Boeing experimental investigations have been conducted to determine the aeropropulsive characteristics of an advanced tactical fighter designed for supersonic cruise. These investigations were conducted in the NASA Langley 16-Foot Transonic and NASA Lewis 10 x 10-Foot Supersonic Wind Tunnels at Mach numbers from 0.60 to 2.47. This fighter is a Mach 2.0, 49,000 pound class vehicle that features a close-coupled canard and underwing propulsion units that utilize multifunction two-dimensional exhaust nozzles. Tests were conducted to determine the basic aerodynamic characteristics of the configuration with flow-through nacelles in which the spillage effects of representative inlets were measured. The effects of thrust-induced forces on overall aerodynamic performance were evaluated with a series of multifunction nozzles installed on air-powered nacelles. An axisymmetric nozzle configuration was also tested to obtain comparative aeropropulsive performance. Trim aerodynamic characteristics for the flow-through and powered configurations and the effect of thrust vectoring at subsonic speeds are presented.

81. HERRING, R. N.; MILLER, D. H.: **Study of potential for sustained supersonic cruise military aircraft utilizing advanced technologies: Optimized fighter and interceptor concepts.** NASA-CR-172337 NAS 1.26:172337 MDC-A8710 1984. 84X10308 US GOV AGENCIES AND CONTRACTORS

Selected component and systems optimizations were conducted for three major areas of fighter aircraft design: aerodynamic configuration, propulsion system, and structural concepts and materials. An air defense study, including a mission analysis and sizing of an interceptor

configuration, was conducted. These conceptual design activities extend a previous study of advanced supersonic cruise military aircraft. The resultant interceptor configuration has a takeoff gross weight of 58,700 lb to perform a Mach 2.0 intercept at a mission radius of 1000 nautical miles. A comparison was made with existing and near term aircraft capabilities for the continental United States (CONUS) interceptor role. These aircraft have far less capability than the advanced configuration.

82. HERRING, R. N.; MILLER, D. H.: **Study of potential for sustained supersonic military aircraft utilizing advanced technologies.** NASA-CR-172222 NAS 1.26:172222 MDC-A7962 1983. 84X10005 US GOV AGENCIES AND CONTRACTORS

The extent to which NASA supersonic cruise research is applicable to future tactical fighters was assessed to two missions: Mission A with a 500 NM radius at Mach 2 on internal fuel and Mission B with a 1000 NM subsonic radius followed by a 500 NM supersonic radius. Fighter class maneuvering performance objectives were established to assure realistic wing loading and thrust-to-weight ratios. A highly swept double delta arrow wing provided an attractive solution for both missions. Configuration parametrics were then conducted to optimize the design to the two missions. Variables included wing aspect and thickness ratios, vertical tail location, inlet and nozzle shape, and engine cycle. The resulting designs weighed approximately 38,000 lbs for Mission A and 57,000 lbs for Mission B. The impact of SCR technologies on these aircraft was assessed one by one. The most important were the advanced engines and composite structures. It was concluded that a majority of SCR is applicable to fighter aircraft and that these technologies will be major contributors to system affordability.

83. BEISSNER, F. L., JR.; LOVELL, W. A.; ROBINS, A. W.; SWANSON, E. E.: **Effect of advanced technology and fuel efficient engine on a supersonic-cruise executive jet with a small cabin.** NASA-CR-172190 NAS 1.26:172190 1983. 83N33876

An analytical study of a supersonic-cruise, executive, jet aircraft indicated the effects of using advanced technology. The twin-engine, arrow-wing vehicle was configured with a cabin of minimum practical size to hold one pilot, eight passengers, and their baggage. The primary differences between this configuration that of a previous report were the reduction in cabin size and the use of engines that are more fuel-efficient. Both conceptual vehicles are capable of forming the same mission. The current vehicle has a range of 3,350 nautical miles at Mach 2.3 cruise and 2,700 nautical miles at Mach 0.9. The concept description includes configuration definition, aerodynamic and propulsion-system characteristics, and mass properties. Performance analyses are documented for intercontinental and transcontinental flight profiles. In the latter case, a reduction in sonic-boom overpressure from 1.3 to 1.0 pounds per square foot was achieved by varying the flight profile slightly from that for optimum performance.

84. TORENBEEK, E.: **On the conceptual design of supersonic cruising aircraft with subsonic wing leading edges.** Delft Progress Report, vol. 8, Jan. 1983, p. 55-80. 83A38950

Applying results from slender wing and slender body theories, a derivation is given for the overall drag coefficient of supersonic cruising aircraft. Using this simplified computational model, applicable to conceptual designs, the qualitative effects of variations in some major shape parameters and design conditions on the lift/drag (L/D) ratio are discussed. Generalized analytical solutions are presented, resulting in a maximum or optimum L/D ratio, for configurations with discrete wing and fuselage, and for integrated configurations. The design variables are wing loading, wing semi-span to length ratio ('box ratio'), fuselage slenderness ratio, and cruise altitude. In addition to the L/D ratio, the mass fraction of fuel and powerplant installation has been used as a figure of merit. An example illustrating the differences between the concepts and the sensitivity of the optimum indicates that the drag model, in spite of its simplicity, yields a reasonably accurate approximation.

85. BEISSNER, F. L., JR.; LOVELL, W. A.; ROBINS, A. W.; SWANSON, E. E.: **Effect of advanced technology and fuel efficient engine on a supersonic-cruise executive jet with a small cabin.** NASA-CR-172190 NAS 1.26:172190 1983. 83N33876

An analytical study of a supersonic-cruise, executive, jet aircraft indicated the effects of using advanced technology. The twin-engine, arrow-wing vehicle was configured with a cabin of minimum practical size to hold one pilot, eight passengers, and their baggage. The primary differences between this configuration that of a previous report were the reduction in cabin size and the use of engines that are more fuel-efficient. Both conceptual vehicles are capable of forming the same mission. The current vehicle has a range of 3,350 nautical miles at Mach 2.3 cruise and 2,700 nautical miles at Mach 0.9. The concept description includes configuration

definition, aerodynamic and propulsion-system characteristics, and mass properties. Performance analyses are documented for intercontinental and transcontinental flight profiles. In the latter case, a reduction in sonic-boom overpressure from 1.3 to 1.0 pounds per square foot was achieved by varying the flight profile slightly from that for optimum performance.

86. WOOD, R. M.; MILLER, D. S.; BRENTNER, K. S.: **Theoretical and experimental investigation of supersonic aerodynamic characteristics of a twin-fuselage concept.**: NASA-TP-2184 L-15607 NAS 1.61:2184 1983. 83N32776

A theoretical and experimental investigation has been conducted to evaluate the fundamental supersonic aerodynamic characteristics of a generic twin-body model at a Mach number of 2.70. Results show that existing aerodynamic prediction methods are adequate for making preliminary aerodynamic estimates.

87. SUSSMAN, M. B.; UPTON, G.; SEVIGNY, E.; PETIT, J. E.; SCHREFFLER, E. S.; STOECKLIN, R. L.; GOETZ, G. F.: **Study of potential for sustained supersonic cruise military aircraft utilizing advanced technologies, volume 1.** NASA-CR-165957 NAS 1.26:165957 D180-270781-1-VOL-1 1982. 82X10336 <u>US GOV AGENCIES AND CONTRACTORS</u>

Advanced technologies developed by NASA for commercial supersonic transport application were assessed for applicability to the military role. Two specific military missions were prescribed and aircraft configurations developed through parametric analysis and optimization. Key technologies were then evaluated in terms of vehicle gross weight impact. Research and development recommendations resulting from these analyses were formulated. Variable camber and vortex flap leading edges, advanced engine cycles propulsive lift, arrow wing/wing body blending, active controls, digital avionics, advanced structural materials, and thermal management are addressed.

88. Large Payload capacity SST concepts: Technical and economic feasibility. NASA-CR-165934 D6-51315 NAS 1.26:165934 1982. 82X10257 <u>US GOV AGENCIES AND CONTRACTORS</u>

A matrix of configuration possibilities for large payload capacity (500 to700 passengers), supersonic transport configurations was investigated. The matrix of fuselages included circular, double deck, side-by-side multilobe, and twin body options. Integration with delta and arrow wing planforms was studied. It is concluded that a number of fuselage options can be integrated into practical SST configuration concepts for the 500 to700 passenger size.

89. BABER, H. T., JR.: **Characteristics of an Advanced Supersonic Technology Transport (AST-106-1) configured variable cycle engines for transpacific range.** NASA-TM-81879 L-14762 NAS 1.15:81879 1982. 82X10157 <u>US GOV AGENCIES AND CONTRACTORS</u>

An advanced supersonic technology (AST) transport configuration (AST-106-1) was defined by application of the following: an extensive aerodynamic data base; several computer programs such as aircraft sizing and performance, takeoff and approach performance, and noise prediction; and a new engine concept which has potential for noise reduction attributable to the coannular nozzle. This configuration has a transpacific range capability of 8438km (4556 n.mi.) when cruising at a Mach number of 2.62 on a hot day (standard-day temperature + 8 C) with 273 passengers. Centerline and sideline traded noise are both in excess of the Federal Aviation Regulation limit. However, it appears that takeoff with accelerating climb followed by engine cutback can reduce the land area enclosed by the 108 EPNdB noise contour to about one-third that for the non-cutback condition. With a ticket price of approximately $220 (1976 dollars) for 100-percent load factor, the configuration could yield a rate of return of 15 percent.

90. DACOSTA, R. A.; ESPIL, G. J.; EVEREST, D. L., JR.; LOVELL, W. A.; MARTIN, G. L.; SWANSON, E. E.; WALKLEY, K. B. : **Concept development studies for a Mach 2.7 supersonic cruise business jet.** NASA-CR-165705 1981. 81X10218 <u>NASA AND NASA CONTRACTORS</u>

The development of a revised and improved version of an advanced supersonic cruise business jet aircraft concept is discussed. The impact of applying advanced technologies on the performance and characteristics of this type vehicle was determined. The aircraft was configured for a maximum cruise Mach number of 2.7. Performance analysis was conducted at Mach 2.62 cruise on a standard plus 8 C day condition for a 5926 km (3200 n.mi.) range with a payload of 8 passengers plus baggage. Superplastic formed/diffusion bonded primary structure was assumed and resulted in a maximum gross weight of 284,686 N (64,000 lbf).

91. ROWE, W. T.: **Technology study for advanced supersonic cruise vehicles.** NASA-CR-165723 MDC-J4668 1981. 81X10344 US GOV AGENCIES AND CONTRACTORS

Technologies and research programs were evaluated for development of a solid technology base from which an advanced supersonic cruise aircraft can be derived. Propulsion technology and structural technology studies result in a range improvement of 5 percent for the Mach 2.2 baseline aircraft. Configuration studies to increase the passenger capacity to 350 at maximum takeoff gross weight of 340,200 kg are complete. Test of an improved supersonic cruise vehicle wing verify that current analytical performance estimating methods are accurate. Structural analysis of applications of SPF/DB titanium sandwich in detail design sows substantial payoff in weight and cost of fabrication. Propulsion integration studies update the technology for the variable cycle engines and suppression schemes to a 1984 go-ahead date. The improved performance data are summarized for six different engines.

92. Advanced concept studies for supersonic vehicles. NASA-CR-165771 Document contains a microfiche supplement 1981. 82X10002 US GOV AGENCIES AND CONTRACTORS

93. ROWE, W. T.; WELGE, H. R.; JOHNSON, E. S.; ROCHTE, L. S. : **Advanced supersonic transport propulsion and configuration technology improvements.**: AIAA PAPER 81-1595 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 13 p. 81A40970

This paper presents the results of recent Douglas Aircraft Company integration studies for an advanced supersonic transport. The studies include technology improvements such as superplastic formed and diffusion-bonded titanium sandwich primary structure, composite secondary structure, bicone engine inlet, improved mechanical suppressors based on flight test data, improved aerodynamic efficiency based on wind tunnel test data, and updated performance for both variable-cycle and low-bypass-ratio engines. Technology development requirements for an economically viable and environmentally acceptable advanced supersonic transport are defined through these studies. A new Douglas Aircraft Company baseline supersonic transport designed to carry 350 passengers is defined for cost comparisons.

94. KELLY, R. J.: **Supersonic cruise vehicle research/business jet.** 1980. 81N18022

A comparison study of a GE-21 variable propulsion system with a Multimode Integrated Propulsion System (MMIPS) was conducted while installed in small M = 2.7 supersonic cruise vehicles with military and business jet possibilities. The 1984 state of the art vehicles were sized to the same transatlantic range, takeoff distance, and sideline noise. The results indicate the MMIPS would result in a heavier vehicle with better subsonic cruise performance. The MMIPS arrangement with one fan engine and two satellite turbojet engines would not be appropriate for a small supersonic business jet because of design integration penalties and lack of redundancy.

95. ROENSCH, R. L.; PAGE, G. S.: **Analytic development of improved supersonic cruise aircraft based on wind tunnel data.** 1980. 81N17989

Data obtained from the MD/NASA cooperative wing tunnel program were used to develop empirical corrections to theory. These methods were then used to develop a 2.2M supersonic cruise aircraft configuration with a cruise trimmed maximum L/D of 10.2. The empirical corrections to the theory are reviewed, and the configuration alternatives examined in the development of the configuration are presented. The benefits of designing for optimum trimmed performance, including the effects of the nacelles, are discussed.

96. MARTIN, G. L.; WALKLEY, K. B.: **Aerodynamic design and analysis of the AST-204, AST-205, and AST-206 blended wing-fuse large supersonic transport configuration concepts.**: NASA-CR-159223 1980. 80N20232

The aerodynamic design and analysis of three blended wing-fuselage supersonic cruise configurations providing four, five, and six abreast seating was conducted using a previously designed supersonic cruise configuration as the baseline. The five abreast configuration was optimized for wave drag at a Mach number of 2.7. The four and six abreast configurations were also optimized at Mach 2.7, but with the added constraint that the majority of their structure be common with the five abreast configuration. Analysis of the three configurations indicated an improvement of 6.0, 7.5, and 7.7 percent in cruise lift-to-drag ratio over the baseline configuration for the four, five, and six abreast configurations, respectively.

97. Technology application study of a supersonic cruise vehicle. NASA-CR-159276 MDC-J4647 1980. 80X10115 US GOV AGENCIES AND CONTRACTORS

The work is summarized for the NASA Supersonic Cruise Vehicle Technology Application Studies. These efforts support the NASA program of applying and evaluating the supersonic technologies available and in defining research programs for improving the technology base for deriving an advanced supersonic cruise aircraft. Aerodynamic, structural propulsion and configuration technology integration studies of the Mach 2.2 baseline show significant refinements which improve range performance. Aerodynamic refinements based on the cooperative NASA/MDC high speed wind tunnel model results and structural refinements with the MDC unique titanium superplastic forming/diffusion bonding sandwich fabrication technique result in a 15 percent range improvement. An additional 1 percent range improvement is obtained by improving the wing thickness and thickness distributions. Analysis of NASA speed model test data reveals that significant wing leading edge thrust of NASA high speed supersonic cruise Mach numbers. The development of analysis methods and integration indicates a possible improvement in aerodynamic cruise efficiency (1/D) of percent. Low speed model wind tunnel test results are compared with analytical data for wing leading and trailing edge devices deflected. These data are used for aerodynamic performance predictions and for the MDC fixed base simulator in real-time with pilot in the loop to study and refine the active control systems. Also, the pressure data are incorporated into the structural analysis program for validation of design conditions.

98. GOEBEL, T. P.; BONNER, E.: **Advanced supersonic cruise aircraft blended wing/body study.** NASA-CR-159289 1980. 80X10122 NASA AND NASA CONTRACTORS

The potential improvement in AST performance due to wing-body blending was investigated. Wing leading edge planform blending was relatively small due to high sweepback angle (74 deg) of the baseline leading edge. Wing trailing edge blending to provide good low speed flap effectiveness results in a drag penalty at supersonic cruise. Optimization to achieve minimum volume wave drag or total wave drag transferred wing volume to the fuselage with minimal cross-section blending. Optimization to minimize drag due to lift had to be constrained to give a practical mounting of the wing onto the fuselage. Viscous optimization was implicitly pursued by minimizing wetted area consistent with volume requirements. A transport configuration was defined by allowing optimization programs to seek the best wing body shape with understanding axisymmetric nacelles. Due to reduced drag and structural weight, 6 to 14% less block fuel per passenger/kilometer (n.mi.) was used than in three earlier unblended transport studies.

99. CARICHNER, G. E.: **Investigation of a Mach 2.55 cruise aircraft design with an over/under engine arrangement at Mach numbers equal 0.6 to 2.7.** NASA-CR-159314 LR-29502 1980. 80X10230 US GOV AGENCIES AND CONTRACTORS

A high speed wind tunnel was developed which is based on a supersonic cruise vehicle configuration which places the engines in an over/under rather than the conventional four engines under the wing arrangement. The wing was cambered for minimum induced drag at a cruise Mach number of 2.55. An aerodynamic data base (force and pressure) was generated for the SCV configuration from tests conducted in 4 feet by 4 feet wind tunnel. The data were obtained to assess the aerodynamic prediction capability of known analysis methods. The test data indicate that the over/under engine arrangement poses no unusual drag problem as compared to the conventional four under configuration. A wide body (8 abreast rather than 6 abreast seating) configuration was also tested, and the data indicates a 6-7 percent lower L/D. Aerodynamic data comparisons between theory and experiment show fair agreement for the wing body near the 2.55 design Mach number. The agreement with predicted drag, however, is poor for off design Mach numbers and/or when nacelles are added.

100. CLAUSS, J. S., JR.; BRUCKMAN, F. A.; BANGERT, L. H.; CARICHNER, G. E.; GUESS, M. K., JR.; HAYS, A. P.; JUREY, L.; SAKATA, I. F.: **Supersonic cruise vehicle technology assessment study of an over/under engine concept, volume 1.** NASA-CR-159247-VOL-1 LR-29363-VOL-1 1980. 80X10103 US GOV AGENCIES AND CONTRACTORS

The variation of supersonic cruise lift-drag ratio, weight, and mission range due to arrow wing planform changes such as sweep, aspect ratio and notch ratio were studied. Airframe/propulsion integration systems were also studied. Inlet technology and low speed aerodynamic/acoustic tasks for supersonic inlets were included. Preferred inlets were selected for Mach 2.0 and 2.3 cruise speeds and the performance compared with that for Mach 2.55 baseline vehicles. A preferred auxiliary inlet system was selected for the aero/acoustic task; preliminary model design and formulation of a test plan also were accomplished. Problems associated with takeoff noise reduction were addressed by optimizing flap and

throttle schedules as well as flight path shape. Both heuristic and mathematical optimization approaches were included. The application of active controls technology to a supersonic cruise vehicle was assessed with respect to the integration of requirements for longitudinal handling qualities, flutter suppression and dynamic load and ride quality characteristics associated with gust response. A family of aluminum alloys were developed having specific properties comparable to titanium alloys.

101. CLAUSS, J. S., JR.; BRUCKMAN, F. A.; BANGERT, L. H.; GARICHNER, G. E.; GUESS, M. K., JR.; HAYS, A. P.; JUREY, L.; SAKATA, I. F.: **Supersonic cruise vehicle technology assessment study of an over/under engine concept, volume 2.** NASA-CR-159247-VOL-2 LR-29363-VOL-2 1980. 80X10104 US GOV AGENCIES AND CONTRACTORS

The work completed during the FY 1979 NASA LaRC Supersonic Cruise Vehicle Technology Assessment studies is reported. Analytical planform were studied to examine the variation of supersonic cruise lift-drag ratio, weight, and mission range due to arrow wing planform changes such as sweep, aspect ratio and notch ratio. Airframe/propulsion integration studies include inlet technology and low speed aerodynamic/ acoustic tasks for supersonic inlets. Preferred inlets were selected for Mach 2.0 and 2.3 cruise speeds and the performance compared with that for Mach 2.55 baseline vehicles. A preferred auxiliary inlet system was selected for the aero/acoustic task; preliminary model design and formulation of a test plan also was accomplished. Takeoff noise reduction studies address noise attenuation by optimizing flap and throttle schedules as well as flight path shape. Both heuristic and mathematical optimization approaches are included. The application of active controls technology to a supersonic cruise vehicle is assessed with respect to the integration of requirements for longitudinal handling qualities, flutter suppression and dynamic load and ride quality characteristics associated with gust response. The development of a family of aluminum alloys, having specific properties comparable to titanium alloys was initiated.

102. KELLY, R.; TYSON, R. M.; DUNN, K. M.; BERRY, J. V.; SHERRILL, D. E.; LANCON, C. J.; ROBINSON, D. A.; CASSIDY, J. E.: **Study of a small supersonic cruise research business jet.** NASA-CR-159226 NA-79-644 1980. 80X10114 US GOV AGENCIES AND CONTRACTORS

A study was conducted to define a small supersonic cruise vehicle which could validate the critical supersonic cruise technologies. The study involved a comparison of a 1984state-of-the-art (SOA) multimode integrated propulsion system (MMIPS) and a 1984 SOA GE21 variable cycle engine (VCE) propulsion system installed in a small supersonic cruise vehicle capable of carrying eight to ten passengers. The aircraft were designed for a transatlantic range of 5926 km (3200 n mi) with cruise at M = 2.7. The aircraft were sized to the same range, constrained to a 2591 m (8500 ft) balanced field length, and then compared at the same sideline noise level.The MMIPS was found to be the heavier propulsion system, although it had superior performance except in the supersonic cruise leg. The single inlet requirement for MMIPS when installed in a small vehicle was a major penalty.

103. Advanced concept studies for supersonic vehicles. NASA-CR-159244 D6-48864 1980. 80X10116 US GOV AGENCIES AND CONTRACTORS The characteristics and research requirements are defined for future supersonic cruise aircraft that would offer superior performance, reduced fuel consumption, and less noise and environmental impact, as well as economical acquisition and operational cost. Many technical advances important to the design of supersonic cruise aircraft are reported, and it is shown that their integration into practical airplane design concepts is feasible.

104. MASCITTI, V. R.; MAGLIERI, D. J.: **Noise and performance calibration study of a Mach 2.2 supersonic cruise aircraft.** NASA-TM-80043 1979. 79N21869

The baseline configuration of a Mach 2.2 supersonic cruise concept employing a 1980 - 1985 technology level, dry turbojet, mechanically suppressed engine, was calibrated to identify differences in noise levels and performance as determined by the methodology and ground rules used. In addition, economic and noise information is provided consistent with a previous study based on an advanced technology Mach 2.7 configuration, reported separately. Results indicate that the difference between NASA and manufacturer performance methodology is small. Resizing the aircraft to NASA ground rules results in negligible changes in takeoff noise levels (less than 1 EPNdB) but approach noise is reduced by 5.3 EPNdB as a result of increasing approach speed. For the power setting chosen, engine oversizing resulted in no reduction in traded noise. In terms of summated noise level, a 6 EPNdB reduction is realized for a 5% increase in total operating costs.

105. WRIGHT, B. R.; CLAUSS, J. S.; AVERETT, B. T.; OATWAY, T. P.; HAYS, A. P.; SAKATA, I. F.: **Supersonic cruise vehicle technology assessment study of an over/under engine concept, volume 1.** NASA-CR-159003-VOL-1 LR-28841-VOL-1 1979. 79X10014 US GOV AGENCIES AND CONTRACTORS

The effects of arrow-wing planform geometry variations on airplane low speed handling qualities is investigated using piloted flight simulation techniques. Baseline aircraft engine airframe integration and installation studies increased aircraft range and defined more realistic engine nacelle designs. Alternative engine candidates were investigated. Advantages of integrated digital control for engines are identified. A design performance, and noise comparison study was conducted on axisymmetric mixed-compression inlets featuring translating and collapsing bi-cone centerbodies in conjunction with auxiliary inlets. A noise cost sensitivity study was completed. Parametric aircraft weight estimating methods were further validated for application to arrow-wing designs. Advantages of Ti-15-3 beta alloy over Ti-6-4 alloy was experimentally verified.

106. YIP, L. P.: **Low-speed wind-tunnel tests of a 1/10-scale model of an advanced arrow-wing supersonic cruise configuration designed for cruise at Mach 2.2.**: NASA-TM-80152 1979. 80N10135

The low-speed longitudinal and lateral-directional characteristics of a scale model of an advanced arrow-wing supersonic cruise configuration were investigated in tests conducted at a Reynolds number of 4.19 x 10 to the 6th power based on the mean aerodynamic chord, with an angle of attack range from - 6 deg to 23 deg and sideslip angle range from -15 deg to 20 deg. The effects of segmented leading-edge flaps, slotted trailing-edge flaps, horizontal and vertical tails, and ailerons and spoilers were determined. Extensive pressure data and flow visualization pictures with non-intrusive fluorescent mini-tufts were obtained.

107. WALKLEY, K. B.; MARTIN, G. L.: **Aerodynamic design and analysis of the AST-200 supersonic transport configuration concept.** NASA-CR-159051 1979. 79N22046

The design and analysis of a supersonic transport configuration was conducted using linear theory methods in conjunction with appropriate constraints. Wing optimization centered on the determination of the required twist and camber and proper integration of the wing and fuselage. Also included in the design are aerodynamic refinements to the baseline wing thickness distribution and nacelle shape. Analysis to the baseline and revised configurations indicated an improvement in lift-to-drag ratio of 0.36 at the Mach 2.7 cruise condition. Validation of the design is planned through supersonic wing tunnel tests.

108. JOHNSON, E. S.: **Advanced technology engine integration/acoustic study.** NASA-CR-159298 MDC-J4601 1978. 80X10128 US GOV AGENCIES AND CONTRACTORS

The integration and evaluation near term and advanced technology low bypass engines and advanced technology variable cycle engines using the MDC 2.2M baseline supersonic airplane is reported. The mission and acoustics performance of the airplane with each engine installed is determined. An analysis of each engine airplane combination is conducted to determine the effect of the engine on the configuration, weight, strength, mission performance, and resulting noise. Resulting capabilities included ranges up to 4150 n.mi. for the near term low bypass engines, 4800 n.mi. for the intermediate term (1982) low bypass engines, and 4900 n.mi. for the intermediate term advance technology variable cycle

109. CLAUSS, J. S., JR.; HAYS, A. P.; WILSON, J. R.: **The common case study: Lockheed design of a supersonic cruise vehicle.** NASA-CR-158935 LR-28705 1978. 78N33086

The objective was to compare the characteristics of SSTs designed for the same mission by Lockheed, McDonnell Douglas, British Aerospace (U.K.), Aerospatiale (France), and the USSR. This comparison was to be used to calibrate parametric design studies of the tradeoff between SST direct operating cost (DOC) and noise levels at the FAR 36 certification points. The guidelines for this common case study were to design an aircraft with the following mission: payload 23 247 kg (51 250 lbm), range - 7000 km (3780 n. mi.), and cruise Mach number - 2.2. Field length was constrained to 3505 m (11 500 ft). Other airfield constraints and fuel reserves were also specified, but no noise constraints were applied.

110. HAYS, A. P.; CLAUSS, J. S., JR.: **Noise cost sensitivity studies for a supersonic cruise vehicle with an over/under engine concept** : NASA-CR-158295 LR-28598 1978. 79X10085 US GOV AGENCIES AND CONTRACTORS

The relationship was studied between predicted noise levels at the FAR Part 36 measurement points and predicted direct operating costs (DOC) for an SST with a specified mission, thereby assessing the feasibility of meeting FAR Part 36 (1969) noise requirements and identifying the associated DOC penalties. Various configuration and operational procedures/options were applied to a baseline configuration incorporating late 1980'slevel technology. These options include thrust-weight ratio and wing loading variation, alternate engine cycles, mechanical suppressors, partial power takeoffs, and programmed throttle takeoffs. The cost model uses the ATA 1967 method modified for airline experience and supersonic operations. The noise model considers three sources: jet mixing noise, forward-radiated fan noise, and airframe noise. Results from these analytical predictions indicate that noise levels slightly below FAR 36 (1969) values are achievable for modest DOC penalties. The results show that a combination of noise relief options investigated is required; e.g.,variable geometry cycle engine plus inverted flow coannular nozzle plus mechanical suppressor in the high velocity stream combined with a partial power takeoff.

111. WRIGHT, B. R.; CLAUSS, J. S.; AVERETT, B. V.; OATWAY, T. P.; HAYS, A. P.; SAKATA, I. F.: **Supersonic cruise vehicle technology assessment study of an over/under engine concept. Volume 2: Appendixes.** NASA-CR-159003-VOL-2 1978. 79X10015 US GOV AGENCIES AND CONTRACTORS

Volume 2 of a two volume report is presented. This volume contains appendixes to Volume 1 and presents data and discussion on the following topics: (1) low-speed wind tunnel test L-423; (2) noise/cost sensitivity configuration data; (3) Pratt and Whitney aircraft engines; (4) General Electric Company engines; and (5) jet noise shielding theory.

112. WRIGHT, B. R.; BRUCKMAN, F. A.; WILSON, J. R.; GUINN, W. A.; SAKATA, I. F.: **Supersonic cruise vehicle technology assessment study of an over/under engine concept.** NASA-CR-145285 LR-28359 1977. 78X10028 US GOV AGENCIES AND CONTRACTORS

Four distinct areas were studied: planform refinement, engine cycle, noise sensitivity, and structures technology. Two arrow wing planforms were identified which meet low-speed requirements while displaying competitive mission performance. More realistic integrated engine/nacelle designs were developed, and the advantages of an integrated digital propulsion control were identified. An optimized aircraft was configured for each engine installation. A noise sensitivity study was initiated to investigate the impact of noise reduction technology on aircraft economics. A low cost titanium manufacturing method utilizing room temperature processing of skin details which features the meta-stable beta titanium alloy was identified. A superplastic forming/diffusion bonding technology application study addressed potential cost and mass savings over current titanium manufacturing techniques. The advanced controls concepts study investigated the feasibility and mass reduction potential of active controls on the supersonic airframe design.

113. **Technology application study of a supersonic cruise vehicle.** NASA-CR-145287 1977. 78X10029 US GOV AGENCIES AND CONTRACTORS

Systems analysis and integration studies were conducted to define a new baseline configuration. The resulting configuration was based on analysis in the areas of aerodynamics, structures, mass properties, and configuration control. Other topics discussed include: (1) active control system analysis; (2) aerodynamic reoptimization from model data; (3) determination of minimum gage titanium; (4) advanced structural analysis and tests; (5) flexible fuselage/landing gear studies; (6) operational requirements; (7) climatic impact assessment; (8) aerodynamic design of low speed wind tunnel models; and (9) inlet design analysis.

114. RADKEY, R. L.; WELGE, H. R.; ROENSCH, R. L.: **Aerodynamic design of a Mach 2.2 supersonic cruise aircraft.** AIAA PAPER 76-955 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Meeting, Dallas, Tex., Sept. 27-29, 1976, 10 p. 1976. 76A47689

The McDonnell Douglas Corporation has conducted numerous Mach 2.2 supersonic aircraft design and integration studies in support of the NASA Supersonic Cruise Aircraft Research (SCAR) program. This paper traces the evolution of a baseline study configuration and an improved performance configuration through several aerodynamic design and trade study cycles. The impact of real-world constraints on configuration design is discussed.The results of a wind-tunnel test of two configurations are presented, and comparisons of analytical and experimental results are shown. This work has demonstrated high L/Ds at Mach 2.2 for a structurally feasible arrow wing configuration.

115. BREWER, G. D.; MORRIS, R. E.: **Minimum energy, liquid hydrogen supersonic cruise vehicle study.** NASA-CR-137776 LR-27347 1975. 76N17101

The potential was examined of hydrogen-fueled supersonic vehicles designed for cruise at Mach 2.7 and at Mach 2.2. The aerodynamic, weight, and propulsion characteristics of a previously established design of a LH2 fueled, Mach 2.7 supersonic cruise vehicle (SCV) were critically reviewed and updated. The design of a Mach 2.2 SCV was established on a corresponding basis. These baseline designs were then studied to determine the potential of minimizing energy expenditure in performing their design mission, and to explore the effect of fuel price and noise restriction on their design and operating performance. The baseline designs of LH2 fueled aircraft were than compared with equivalent designs of jet A (conventional hydrocarbon) fueled SCV's. Use of liquid hydrogen for fuel for the subject aircraft provides significant advantages in performance, cost, noise, pollution, sonic boom, and energy utilization.

116. Advanced concept studies for supersonic vehicles.: NASA-CR-165771 Document contains a microfiche supplement 1981. 82X10002 <u>US GOV AGENCIES AND CONTRACTORS</u>

1.3 SURVEYS ON PROPULSION

117. ALLEN, G. E.; CHAMPAGNE, G.; KLEIN, H. L.; ADLER, R. : **Benefits of advanced materials, structures, and aerodynamics in future high speed civil transport propulsion systems.**: AIAA PAPER 90-3285 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Conference, Dayton, OH, Sept. 17-19, 1990. 9 p. 1990. 90A48872

Recent studies conducted under the NASA sponsored High Speed Civil Transport (HSCT) program have indicated that a significant market opportunity exists for a 2nd generation supersonic commercial transport by the early 21st century. The aircraft must be economically competitive with a subsonic transport fleet and meet stringent environmental constraints, particularly in relation to community noise and nitrous oxide emissions. The propulsion system represents a critical element in achieving an economically affordable, environmentally acceptable High Speed Civil Transport. This paper identifies key propulsion system material, structural, and aerodynamic technologies required for an integrated HSCT aircraft/propulsion system designed for a 5000 nautical mile Mach 3.2 cruise. The benefits of these key technologies are also presented in terms of aircraft takeoff gross weight, fuel consumption, and cruise Nox emissions.

118. STRACK, WILLIAM C.: **Propulsion challenges and opportunities for high-speed transport aircraft.** In its Aeropropulsion '87. Session 6: High-Speed Propulsion Technology, 19 p (See 88N15807) 1987. 88N15809

For several years there was a growing interest in the subject of efficient sustained supersonic cruise technology applied to a high-speed transport aircraft. The major challenges confronting the propulsion community for supersonic transport (SST) applications are identified. Both past progress and future opportunities are discussed in relation to perceived technology shortfalls for an economically successful SST that satisfies environmental constraints. A very large improvement in propulsion system efficiency is needed both at supersonic and subsonic cruise conditions. Toward that end, several advanced engine concepts are being considered that, together with advanced discipline and component technologies, promise at least 40 percent better efficiency that the Concorde engine. The quest for higher productivity through higher speed is also thwarted by the lack of a conventional, low-priced fuel that is thermally stable at the higher temperatures associated with faster flight. Airport noise remains a tough challenge because previously researched concepts fall short of achieving FAR 36 Stage 3 noise levels. Innovative solutions may be necessary to reach acceptably low noise. While the technical challenges are indeed formidable, it is reasonable to assume that the current shortfalls in fuel economy and noise can be overcome through an aggressive propulsion research program.

119. Integrated flight/propulsion control - Methodology, design, and evaluation. AIAA PAPER 85-3048 AIAA, AHS, and ASEE, Aircraft Design Systems and Operations Meeting, Colorado Springs, CO, Oct. 14-16, 1985. 24p 86A10927

Details of the activities performed during each of four phases of the U.S.A.F. Design Methods for Integrated Control Systems program which produced a set of integrated flight/propulsion control laws are summarized. Phase I produced the integrated control system design requirements for STOL, terrain following/threat avoidance/obstacle avoidance, air-to-air combat maneuvering, air-to-surface combat maneuvering, and supersonic cruise. Phase II work yielded a nonlinear simulation model for steady-state and dynamic

characteristics of the aircraft, inlet, engine and nozzle, using a modified F-16XL as the test bed. The design and development of the control logic for each mission segment were accomplished in Phase IV, with the logic being evaluated with the Phase III simulation model.

120. SAUNDERS, N. T.; GLASSMAN, A. J.: **Future directions in aeropropulsion technology**.: NASA-TM-87010 E-2553 NAS 1.15:87010 1985. 85N23685

Future directions in aeropropulsion technology that have been identified in a series of studies recently sponsored by the U.S. Government are discussed. Advanced vehicle concepts that could become possible by the turn of the century are presented along with some of their projected capabilities. Key building-block propulsion technologies that will contribute to making these vehicle concepts a reality are discussed along with projections of their status by the year 2000. Some pertinent highlights of the NASA aeropropulsion program are included in the discussion.

121. HOUCHARD, J. H.; CARLIN, C. M.; TJONNELAND, E.: **Inlet, engine, airframe controls integration development for supercruising aircraft**.: International Symposium on Air Breathing Engines, 6th, Paris, France, June 6-10, 1983, Symposium Papers (83A35801 16-07). New York, American Institute of Aeronautics and Astronautics, 1983, p. 342-356. 83A35842

In connection with a consideration of advanced military aircraft systems, attention is given to research for improving the technology of the design of supersonic cruise aircraft. Syberg et al. (1981) have shown that an analytic design method is now available to accurately predict the flow characteristics of axisymmetric supersonic inlets, including off-design angle of attack operation. On the basis of information regarding the inlet flow characteristics, the control system designer can begin the inlet design and development, before wind tunnel testing has begun. The present investigation is concerned with details and status of inlet control technology. A detailed representation of a supersonic propulsion system is developed. This development demonstrates the feasibility of the selected hybrid computational concept.

122. Aerodynamics of power plant installation. AGARD-CP-301 ISBN-92-835-0301-5 AD-A108300 1981. 82N13065

123. HADALLER, O. J.; SCHMIDT, J. E.; MOMENTHY, A. M.; JOHNSON, P. E.: **Impact of changing fuel characteristics on supersonic cruise airplane**. 1980. 81N18018

The question of an advanced supersonic cruise research airplane is related to future oil supplies and prices. Technical data on the impact of changing fuel characteristics on the SCR airplane were developed. Projections of crude oil characteristics typical of the 1985 to 2000 time period were made with the help of consultants to the oil industry. Refineries for the future were modeled to establish jet fuel of engine and aircraft systems for future airplanes, with emphasis on supersonic cruise airplanes. Study results do not show a need for broadening the fuel specification. Hypothetical study fuels with broader specifications were defined, however, as was the impact of their properties on the SCR airplane and systems.

124. STEWART, W. L.: **NASA research in aeropropulsion**. 1980. 81N12980

The role of the Lewis Research Center in aeronautical propulsion is described. The state of the art in engine systems and components are discussed and some of the problems that confront the civil and military aeronautic sectors are addressed. Some of the programs that are under way are summarized with emphasis on the future needs and opportunities in aeronautics.

125. POWERS, A. G.; COLTRIN, R. E.; STITT, L. E.; WEBER, R. J.; WHITLOW, J. B., JR.: **Supersonic propulsion technology**. 1979. 80N10216

Propulsion concepts for commercial supersonic transports are discussed. It is concluded that variable cycle engines, together with advanced supersonic inlets and low noise coannular nozzles, provide good operating performance for both supersonic and subsonic flight. In addition, they are reasonably quiet during takeoff and landing and have acceptable exhaust emissions.

126. BRAGDON, E. L.; FOSS, R. L.: **Studies of the impact of advanced technologies applied to supersonic cruise aircraft:** Preliminary propulsion assessment study. NASA-CR-155095 1975. 78X70053 US GOV AGENCIES AND CONTRACTORS

1.4 BIBLIOGRAPHIES

127. BURCHAM, W.: **YF-12 Flight research program results bibliography**: NASA Ames Dryden compilation, Presented at the SR-71 Flight Experience Meeting, NASA Ames Dryden, July 10, 1990.

128. HOFFMAN, S.: **Bibliography of Supersonic Cruise Research (SCR) program from 1980 to 1983.**: NASA-RP-1117 L-15740 NAS 1.61:11171984. 1984. 84N27674

A bibliography for the Supersonic Cruise Research (SCR) and Variable Cycle Engine (VCE) Programs is presented. An annotated bibliography for the last 123 formal reports and a listing of titles for 44 articles and presentations is included. The studies identifies technologies for producing efficient supersonic commercial jet transports for cruise Mach numbers from 2.0 to 2.7.

129. Aircraft sonic boom: Studies on aircraft flight, aircraft design, and measurement. Citations from the NTIS data base PB81-805665 NTIS/PS-79/0264 1981. 81N77103

130. HOFFMAN, S.: **Bibliography of Supersonic Cruise Research (SCR) program from 1977 to mid-1980.**: NASA-RP-1063 L-13764 1980. 81N14973

The supersonic cruise research (SCR) program, initiated in July 1972, includes system studies and the following disciplines: propulsion, stratospheric emission impact, structures and materials, aerodynamic performance, and stability and control. In a coordinated effort to provide a sound basis for any future consideration that may be given by the United States to the development of an acceptable commercial supersonic transport, integration of the technical disciplines was undertaken, analytical tools were developed, and wind tunnel, flight, and laboratory investigations were conducted. The present bibliography covers the time period from 1977 to mid-1980. It is arranged according to system studies and the above five SCR disciplines. There are 306 NASA reports and 135 articles, meeting papers, and company reports cited.

131. TUTTLE, M. H., MADDALON, D. V.: **Supersonic cruise aircraft research: An annotated bibliography.**: NASA-TM-81781 L-13640 1980. 80N21316

This bibliography, with abstracts, consists of 69 publications arranged in chronological order. The material may be useful to those interested in supersonic cruise fighter/penetrator/interceptor airplanes. Two pertinent conferences on military supercruise aircraft are considered as single items; one contains 37 papers and the other 29 papers. In addition, several related bibliographies are included which cover supersonic civil aircraft and military aircraft studies at the Langley Research Center. There is also an author index.

132. NICHOLS, M. R.; **Bibliography on aerodynamics of airframe/engine integration of high-speed turbine-powered aircraft - volume I.**: NASA-TM-81814 L-13251, 90 p. 1980. 81N11032

This bibliography was developed as a first step in the preparation of a monograph on the subject of the aerodynamics of airframe/engine integration of high-speed turbine-powered aircraft. It lists 1535 unclassified documents published mainly in the period from 1955 to 1980. Primary emphasis is devoted to aerodynamic problems and interferences encountered in the integration process; however, extensive coverage also is given to the characteristics and problems of the isolated propulsion-system elements. Annotation of the individual books and papers was not considered practical because of length of the listing. A detailed topic breakdown structure is used instead. The primary contents of the individual documents are indicated by the combination of the document's title and its location within the framework of the bibliography.

133. NICHOLS, M. R.; **Bibliography on aerodynamics of airframe/engine integration of high-speed turbine-powered aircraft - volume II.**: NASA-TM-81815 L-13781-VOL 2, 12 p. 1980. 80X10234 US GOV AGENCIES AND CONTRACTORS

This bibliography was developed as a first step in the preparation of a monograph on the subject of the aerodynamics of airframe/engine integration of high-speed turbine-powered aircraft. Volume I lists 1535 unclassified documents published mainly in the period from 1955 to 1980; this volume contains 101 restricted references for the same period. Primary emphasis is devoted to aerodynamic problems and interferences encountered in the integration process; however, extensive coverage also is given to the characteristics and problems of the isolated propulsion-system elements. Annotation of the individual books and papers was not considered practical because of length of the listing. A detailed topic breakdown structure is used instead. The primary contents of the individual documents are indicated by the combination of the

document's title and its location within the framework of the bibliography.

134. MADDALON, DAL V.; **Military aircraft and missile technology at the Langley Research Center - A selected Bibliography.**: NASA-TM-80204, Jan. 1980, 41 p.

A compilation of reference material is presented on the Langley Research Center's efforts in developing advanced military aircraft and missile technology over the past twenty years. Reference material includes research made in aerodynamics, performance, stability, control, stall-spin, propulsion integration, flutter, materials, and structures.

135. HOFFMAN, SHERWOOD; **Supersonic Cruise Research (SCR) Program publications for FY 1977 through FY 1979 -Preliminary bibliography**: NASA-TM-80184, Nov. 1979, 42 p. 80N11029

This bibliography was prepared for the November 13-16, 1979 SCR Conference at the Langley Research Center and is a preliminary report. It covers the time period from FY 1977 through FY 1979. A previous bibliography, NASA-RP-1003, covers the first five years of the program, 1972 to mid-1977. The present report also includes a few publications which were omitted in the first bibliography and several non SCR papers, which support the program, for completeness. The bibliography is arranged according to System Studies and the five SCR disciplines, as follows: Propulsion, Stratospheric Emissions Impact, Materials and Structures, Aerodynamic Performance, and Stability and Control.

136. NICHOLS, M. R.: **Bibliography on aerodynamics of airframe/engine integration of high-speed turbine-powered aircraft, volume 1**. NASA-TM-81814 L-13251-VOL-1 1980. 81N11032

This bibliography was developed as a first step in the preparation of a monograph on the subject of the aerodynamics of airframe/engine integration of high speed turbine powered aircraft. It lists 1535 unclassified documents published mainly in the period from 1955 to 1980. Primary emphasis was devoted to aerodynamic problems and interferences encountered in the integration process; however, extensive coverage also was given to the characteristics and problems of the isolated propulsion system elements. A detailed topic breakdown structure is used. The primary contents of the individual documents are indicated by the combination of the document's title and its location within the framework of the bibliography.

137. HOFFMAN, SHERWOOD; **Bibliography of Supersonic Cruise Aircraft Research (SCAR) program from 1972 to mid-1977.**: NASA-RP-1003, Nov. 1977, 102 p. 78N12895

This bibliography documents publications of the Supersonic Cruise Aircraft Research (SCAR) Program that were generated during the first 5 years of effort. The reports are arranged according to Systems Studies and five SCAR disciplines: Propulsion, Stratospheric Emissions Impact, and Stability and Control. The specific objectives of each discipline are summarized. Annotation is included for all NASA in-house and low-numbered contractor reports. There are 444 papers and articles included.

138. NICHOLS, M. R.: **Aerodynamics of airframe-engine integration of advanced supersonic aircraft.** NASA-TM-74935 1966. 77X78288 <u>NASA PERS. ONLY</u>

1.5 CONFERENCE PROCEEDINGS

139. POISSON-QUINTON, PH.: **European Symposium on the Future of High Speed Air Transport**,Strasbourg, France, Nov. 6-8, 1989, Proceedings Symposium organized by Academie Nationale de l'Air et de l'Espace; Sponsored by CEC, Ministere de la Recherche et de la Technologie, Direction Generale de l'Aviation Civile, et al. Toulouse, France, Cepadues-Editions, 1990, 375 p. In French and English. For individual items see 91A10952 to 91A10978. 1990. 91A10951

Topics presented include the SST programs in the sixties, NACA/NASA supersonic flight research, Air France experience as a supersonic transport airline, and a NASA view on key technical issues for an advanced high speed commercial transport. Also presented are the sonic boom problem, the advantages and problems of cryogenic fuels for high speed transport, future supersonic transport propulsion optimization, hypersonic transport optimization, the optimization of hybrid propulsion systems, and the need for a hypersonic demonstrator.

140. **Intake aerodynamics, volume 1**. VKI-LS-1988-04-VOL-1 ISSN-0377-8312 ETN-89-93592 1988. 89N16738

141. Intake aerodynamics, volume 2. VKI-LS-1988-04-VOL-2 ISSN-0377-8312 ETN-89-93593 1988. 89N16748

142. BECKER, DOROTHY L.: **Fuels for Future High-Speed Flight Vehicles. Volume 1: JANNAF Ramjet Subcommittee Workshop.**: CPIA-PUBL-518-VOL-1 AD-B141616L 1988. 90X72488 DOMESTIC

143. Propulsion '87. Session 6: High-Speed Propulsion Technology.: NASA-CP-10003-SESS-6 E-3798-SESS-6 NAS 1.55:10003-SESS-6 1987. 88N15807

144. Engine Response to Distorted Inflow Conditions.: AGARD-CP-400 ISBN-92-835-0412-7 AD-A182635 1987. 87N24464

145. Proceedings of the 4th NAL Symposium on Aircraft Computational Aerodynamics.: NAL-SP-7 ISSN-0452-2982 DE88-770071 1986. 88N13253

146. STACK, SHARON H.: **Langley Symposium on Aerodynamics, volume 1** NASA-CP-2397 L-16031 NAS 1.55:2397 1986. 88N14926

147. Aircraft Drag Prediction and Reduction.: AGARD-R-723 ISBN-92-835-1507-2 AD-A160718 1985. 86N15266

148. Special Course on Subsonic/Transonic Aerodynamic Interference for Aircraft.: AGARD-R-712 ISBN-92-835-0332-5 AD-A133675 1983. 84N12072

149. MCKINNEY, L. W.; BAALS, D. D.: **Wind-Tunnel/Flight Correlation, 1981.** NASA-CP-2225 L-15368 NAS 1.55:2225 1982. 82N25196

150. Advanced concept studies for supersonic vehicles.: NASA-CR-165771 Document contains a microfiche supplement 1981. 82X10002 US GOV AGENCIES AND CONTRACTORS

151. Aerodynamics of Power Plant Installation.: AGARD-CP-301 ISBN-92-835-0301-5 AD-A108300 1981. 82N13065

152. Subsonic/Transonic Configuration Aerodynamics.: AGARD-CP-285 ISBN-92-835-0276-0 AD-A094086 1980. 81N15991

153. Supersonic Cruise Research 1979, part 1.: NASA-CP-2108-PT-1 L-13385-PT-1 1980. 81N17981

154. Supersonic Cruise Research 1979, part 2.: NASA-CP-2108-PT-2 L-13385-PT-2 1980. 81N18005

155. Advanced control systems for aircraft powerplants.: AGARD-CP-274 ISBN-92-835-0258-2 1980. 80N26306

156. The use of computers as a design tool.: AGARD-CP-280 ISBN-92-835-0256-6 1980. 80N21243

157. Recent selected papers of Northwestern Polytechnical University. Parts 1 & 2.: Xian, Shaanxi, People's Republic of China, Northwestern Polytechnical University, 1979. Pt. 1, 203 p.; pt. 2, 243 p. In English and Chinese.(For individual items see 81A17802 to 81A17828) 1979. 81A17801

Papers are presented on such topics as the finite difference computation of steady transonic potential flow past aircraft, the design of subcritical airfoils, the synthesis of array antennas of high directivity and low sidelobe, the calculation of the integral-type flexure hinge assembly of dynamically tuned gyroscopes, the structural analysis of fuselages with cutouts, and the solidification characteristics of superalloys. Also considered are the matrix analysis of wings, pulsed spray transfer arc welding, color discrimination by a color-picture reader, the response of a turbojet engine to inlet pressure distortion, and the acoustic instability of solid propellant rocket engines.

158. RIEGELS, F. W.; LAWACZECK, O.: **Contributions to steady and unsteady aerodynamics** DLR-FB-77-34 1977. 78N17004

159. Inlet Workshop: NASA-TM-88783 NAS 1.15:88783 1977. 86N72197

160. Proceedings of the SCAR Conference, part 1.: NASA-CP-001-PT-1 1976. 77N17996

161. ROSKAM, J.: **Proceedings of the NASA, Industry, University, General Aviation Drag Reduction Workshop** NASA-CR-145627 1975. 76N10997

2.0 INLETS

2.1 GENERAL SURVEYS

162. Intake aerodynamics, volume 1. VKI-LS-1988-04-VOL-1 ISSN-0377-8312 ETN-89-93592 1988. 89N16738

163. Intake aerodynamics, volume 2. VKI-LS-1988-04-VOL-2 ISSN-0377-8312 ETN-89-93593 1988. 89N16748

164. LEYNAERT, JACKY: **Transport aircraft intake design**. In VKI, Intake Aerodynamics, Volume 2, 28 p (See 89N16748 09-02) 1988. 89N16749

Subsonic air intake, Mach 2+ transport aircraft intake, and Mach 3 are considered. Hypersonic cruise intakes are mentioned. The problem of supersonic intake adaptation to the intermediate flight Mach number range is reviewed. Future multicycle engine design is discussed.

165. SEDDON, J.; GOLDSMITH, E. L.: **Intake aerodynamics**. New York/London, American Institute of Aeronautics and Astronautics/Collins Professional and Technical Books, 1985, 471 p. 86A18450

A comprehensive physical treatment is presented for the fluid dynamics of both subsonic and supersonic aircraft engine air intakes, first treating internal intake duct flow to the engine, from initial freestream conditions, through successively faster speed regimes, and then proceeding to intake external drag. Attention is given to pressure recovery in subsonic intakes, transonic effects of preentry flow, lip separation and transonic throat flow, external and internal supersonic compression, losses in supersonic intakes, and boundary layer bleeds and diverters. Also discussed are the shock oscillation of supersonic intakes, distortion and swirl phenomena, intakes at incidence, and novel intake designs and related devices.

166. Proceedings of the 12th Navy Symposium on Aeroballistics, volume 2. AD-A111783 1981. 82N27312

Contents: Current Status of Inlet Flow Prediction Methods; Rotational Flow in a Curved-Wall Diffuser Designed by Using the Inverse Method of Solution of Potential Flow Theory; Aerodynamic Characteristics of a Series of Airbreathing Missile Configurations; Parabolized Navier-Stokes Predictions for Three-Dimensional Viscous Supersonic Flows; Results of a Government and Industry Survey of the Heating Methods Used to Determine Missile Structural Temperatures; Supersonic Combustor Insulation Ablation Analysis and Tests; Computation of Three-Dimensional Viscous Flow over Blunt Lifting Bodies at High Angle of Attack; Computation of Hypersonic Laminar Viscous Flow over a Body with Mass Transfer and/or Spin at Angle of Attack; Three-Dimensional Viscous Shock-Layer Analysis of Laminar or Turbulent Flows in Chemical Equilibrium; Further Development of the Streamline Method for Determination of Three-Dimensional Flow Separation; Comparison of Numerical Results and Measured Data for Smooth and Indented Nose tips; Structural and Electrical Performance Considerations in the Design of Multiband Radomes; and Structural Considerations for the Recovery of Air-to-Air Missiles.

167. High-speed cowlings, air inlets and outlets, and internal-flow systems. In its the High-Speed Frontier, p 139-165 (See 81N15969) 1980. 81N15973

A case history is presented of the National Advisory Committee on Aeronautics' program of aircraft engine development. The ramjet engine is described and its development is traced through work done in the field of supersonic inlets. The effects of heat and compressibility on internal flow systems in engines are discussed.

168. BANGERT, L. H.; SANTMAN, D. M.; HORIE, G.; MILLER, L. D.: **Effects on inlet technology on cruise speed selection**. In NASA Langley Research Center Supersonic Cruise Res., 1979, Pt. 1 p 391-411 (See 81N17981 09-01) 1980. 81N17998

The impact of cruise speed on technology level for certain aircraft components is examined. External-compression inlets were compared with mixed compression, self starting inlets at cruise Mach numbers of 2.0 and 2.3. Inlet engine combinations that provided the greatest aircraft range were identified. Results show that increased transonic to cruise corrected air flow ratio gives decreased range for missions dominated by supersonic cruise. It is

also found important that inlets be designed to minimize spillage drag at subsonic cruise, because of the need for efficient performance for overland operations. The external compression inlet emerged as the probable first choice at Mach 2.0, while the self starting inlet was the probable first choice at Mach 2.3. Airframe propulsion system interference effects were significant, and further study is needed to assess the existing design methods and to develop improvements.

169. BANGERT, L. H.; SANTMAN, D. M.; HORIE, G.; MILLER, L. D.: **Some effects of cruise speed and engine matching of supersonic inlet design**. AIAA PAPER 80-1807 American Institute of Aeronautics and Astronautics, Aircraft Systems Meeting, Anaheim, Calif., Aug. 4-6, 1980, 9 p. 80A45734

An analytical study was conducted to determine the impact of flight Mach number on inlet type selection for a supersonic cruise aircraft. External and mixed-compression axisymmetric and two-dimensional inlets were considered. The internal contraction of the mixed-compression inlets was limited to achieve self-starting. At Mach 2.0, the axisymmetric mixed-compression inlet provided the best aircraft range. At Mach 2.3, the two-dimensional mixed-compression inlet was the most attractive if enough variable geometry were incorporated to minimize spillage during subsonic cruise. Increases in takeoff-to-cruise air flow ratio gave lower aircraft range.

170. SHIMABUKURO, K. M.; WELGE, H. R.; LEE, A. C.: **Inlet design studies for a Mach 2.2 advanced supersonic cruise vehicle.** AIAA PAPER 79-1814 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Meeting, New York, N.Y., Aug. 20-22, 1979,11 p. 1979. 79A51247

Various inlet-engine combinations have been studied to find a preferred inlet concept for integration with an advanced technology Mach 2.2 cruise vehicle having a cruise lift-to-drag ratio of 9.6. For the purposes of this study, the range capability for a fixed takeoff gross weight was used to assess the various inlet-engine combinations. Inlet concept selection studies are described which indicated that an axisymmetric, mixed compression inlet was preferred. This study considered four inlet and three engine cycle combinations where the engine airflow was tailored to the inlet airflow delivery capability. Detailed design studies of two mixed compression inlet types are discussed. These were a translating centerbody inlet and a collapsing centerbody bicone inlet. The aerodynamic and mechanical design of each inlet is described. These inlets were also matched to different engine cycles tailored to the inlet airflow capability. The range increments favored the bicone inlet concept primarily because of lighter weight, reduced bleed air, and greater transonic airflow/thrust capability.

171. Inlet Workshop. NASA-TM-88783 NAS 1.15:88783 1977. 86N72197

172. SURBER, L. E.: **Transonic/supersonic inlet R and D past, present, and future**. In NASA Lewis Research Center Inlet Workshop, p 427-480 (See 86N72197 18-01) 1977. 86N72225

173. TINDELL, R.: **High-flow inlets**. In NASA Lewis Research Center Inlet Workshop, p 355-382 (See 86N72197 18-01) 1977. 86N72221

174. WELGE, H. R.: **Methods used at Douglas Aircraft for supersonic inlet design and airframe integration.** In NASA Lewis Research Center Inlet Workshop, p 184-200 (See 86N72197 18-01) 1977. 86N72209

175. BOWDITCH, D. N.: **Supersonic cruise inlets for variable-cycle engines.** In its Proc. of the SCAR Conf., Part 1, p 387-397 (See 77N17996 09-01) 1976. 77N18015

The performance of candidate supersonic cruise inlets is reviewed and the aerodynamic installation penalties for each type are defined. The main characteristics that affect the airflow schedules of variable cycle engines are defined. These schedules are compared with the airflow schedules of the candidate inlets, and appropriate inlets are matched to the variable-cycle engine characteristics. Auxiliary inlets are also considered.

176. BROOKS, A. J.; DADD, G. J.: **Mixed compression air intakes for operation at Mach 2.2.** International Symposium on Air Breathing Engines, 2nd, Sheffield, England, March 24-29, 1974, Proceedings. (74A39964 20-28) London, Royal Aeronautical Society, 1974. 16 p. 1974. 74A39981

Model tests on a series of mixed compression intakes, at conditions equivalent to Mach 2.2 flight, led to the development of an intake bleed arrangement which permitted continuous operation over an adequate mass flow range and with acceptable engine flow distortion levels. An analysis method was developed for comparing

intakes in terms of their effects on payload. This was used to demonstrate a payload performance improvement of 5.5% for the best model tested, relative to typical external compression intakes, with a potential for a further 2% improvement following further development.

177. BROOKS, A. J.; DADD, G. J.: **Mixed compression air intakes for operation at Mach 2.2.** NGTE-R-330 BR42755 1974. 75X71310 US GOV AGENCIES AND CONTRACTORS

178. BOWDITCH, D. N.: **Some design considerations for supersonic cruise mixed compression inlets.**: AIAA PAPER 73-1269 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 9th, Las Vegas, Nev., Nov. 5-7, 1973, AIAA 19 p. 1973. 74A12496

A mixed compression inlet designed for supersonic cruise has very demanding requirements for high total pressure recovery and low bleed and cowl drag. However, since the optimum inlet for supersonic cruise performance may have other undesirable characteristics, it is necessary to establish trade-offs between inlet performance and other inlet characteristics. The paper will review some of these trade-offs between the amount of internal compression, aerodynamic performance and angle-of-attack tolerance. Also some techniques in use at the Lewis Research Center for analysis of boundary layer control and subsonic diffuser flow will be discussed.

179. BOWDITCH, D. N.; COLTRIN, R. E.; SANDERS, B. W.; SORENSEN, N. E.; WASSERBAUER, J. F.: **Supersonic cruise inlets.** In its Aircraft Propulsion 1971, p 283-312 (See 71N19451 09-28) 1971. 71N19460

180. LEWIS, W. G. E.; RETTIE, I. H.: **Design and development of an air intake for a supersonic transport aircraft.** AIAA PAPER 67-752 1968. 69A11014

181. ANDREWS, S. J.: **A summary of aircraft intake investigations carried out by NACA since 1952.** S/T-MEMO-1/56 1956. 82N75825

2.2 AXISYMMETRIC INLETS

182. CHYU, W. J.; KAWAMURA, T.; BENCZE, D. P.: **Navier-Stokes solutions for mixed compression axisymmetric inlet flow with terminal shock.** (AIAA, Aerospace Sciences Meeting, 25th, Reno, NV, Jan. 12-15, 1987, AIAA Paper 87-0160) Journal of Propulsion and Power (ISSN 0748-4658), vol. 5, Jan.-Feb. 1989, p. 4, 5. Abridged. Previously cited in issue 09, p. 1191, Accession no. 87A24932. 1989. 89A22276

183. KAWAMURA, T.; CHYU, W. J.; BENCZE, D. P.: **Numerical simulation of three-dimensional supersonic inlet flow fields.** AIAA PAPER 87-0160. AIAA, Aerospace Sciences Meeting, 25th, Reno, NV, Jan. 12-15, 1987. 13 p. 1987. 87A24932

Supersonic inlet flows with mixed external-internal compressions of an axisymmetric inlet model were computed using a combined implicit-explicit (Beam-Warming-Steger/MacCormack) method for solving the three-dimensional unsteady, compressible Navier-Stokes equations in conservation form. Numerical calculations were made of various flows typically found in supersonic inlets such as shock-wave intersections, flow spillage around the cowl lip, shock-wave/boundary-layer interactions, control of shock-induced flow separation by means of boundary layer bleed, internal normal (terminal) shocks, and the effects of flow incidence. Computed results were compared with available wind tunnel data.

184. MILESHIN, V. I.: **An analysis of supersonic three-dimensional flow past air intakes under conditions of shock spillage.** Zhurnal Vychislitel'noi Matematiki i Matematicheskoi Fiziki (ISSN 0044-4669), vol. 26, Nov. 1986, p. 1704-1718. In Russian. 1986. 87A26323

An analysis is made of supersonic flow of an ideal gas past axisymmetric and nearly axisymmetric bodies with an annular passage and a tapered central body at angle of attack under conditions of shock spillage. The approach used here consists in analyzing the flow on individual meridional half-planes in cylindrical coordinates, with the Godunov finite difference scheme used on each half-plane. An algorithm is proposed for isolating a three-dimensional shock wave whose surface has a singular splitting line (a line of points of triple interaction of compression shocks). The method is illustrated by examples.

185. HOWLETT, D. G.; HUNTER, L. G.: **A study of a supersonic axisymmetric spiked inlet at angle of attack using the Navier-Stokes equations.** AIAA PAPER 86-0308 AIAA, Aerospace Sciences Meeting, 24th, Reno, NV, Jan. 6-9, 1986. 12 p. 1986. 86A22691

Numerical solutions of the 3-D, unsteady, compressible Navier-Stokes equations were obtained for the flow field about an external compression axisymmetric spike inlet at angle-of-attack for a Mach number of 2.0. MacCormack's explicit finite difference algorithm was utilized to obtain the numerical solution. The computational results were able to predict the spike-centerbody and internal cowl pressure for angles-of-attack up to 8 degrees. In addition, the inlet overpressure on the leeward side was also predicted which is a major contribution to inlet unstart. Numerical results are given in terms of Mach number, static pressure, and total pressure contours. Static pressure and pressure recovery comparisons with experimental data are also given.

186. POWELL, A. G.; FRASCA, R. L.; PELLINO, A. G.: **Technology study for advanced supersonic cruise vehicles inlet technology.** NASA- CR-172602 NAS 1.25:172602 1985. 85X10356 US GOV AGENCIES AND CONTRACTORS

Low-speed tests were conducted in the NASA LeRC 9x15 wind tunnel at Mach numbers of 0, 0.1, and 0.2 to measure the aerodynamic and acoustic characteristics of an axisymmetric mixed compression supersonic inlet with variable cowl slot. The inlet model which was powered by the JT8D single-stage fan simulator consisted of the NASA P-inlet centerbody and two cowls. The performance cowl was tested over a range of flows, cowl slot openings, centerbody positions and angles of attack. Total pressure recovery, steady-state and dynamic distortions and selected rake data are presented. The acoustic cowl was tested to determine the acoustic effectiveness of the design absorptive linings. Data were recorded with the variable cowl slot in the full open and closed positions to simulate takeoff and landing operations. Noise measurements were made on an arc around the inlet to obtain directivity information and on various internal surfaces for diagnostic information.

187. BECK, W. E.; JR.; BOCHARY, E.: **Aerodynamic and acoustic performance of an axisymmetric supersonic inlet with auxiliary inlets operating at low speed.** NASA-CR-177962 NAS 1.26:177962 LR-30885 1985. 85X10396 US GOV AGENCIES AND CONTRACTORS

A 1/3 scale model test program was conducted in the NASA LeRC 9x15 ft. Anechoic Wind Tunnel to investigate the low speed aerodynamic and acoustic performance characteristics of a mixed compression, axisymmetric supersonic inlet operating with auxiliary inlets. A JT80 fan simulator was used to pump inlet airflow and to provide engine noise signatures. The model configuration was varied to simulate inlet centerbody spike positions of the full-scale design. Configuration variations also included three auxiliary door shapes with differing auxiliary duct area distributions and two door positions that varied throat area. Test were conducted at tunnel (freestream) Mach numbers of 0, 0.1, and 0.2, and for a range of corrected fan speeds that simulated takeoff and approach conditions. This report presents a summary of the aerodynamic and acoustic test results. Blade passage tone (BPT) sound power levels are plotted versus corresponding inlet compressor face total pressure recovery for all configurations tested.

188. LUO, S.; SHEN, H.; JI, M.; XING, Z.; DONG, S.; HAN,A.: **A mixed finite difference analysis of the internal and external transonic flow fields of inlets with centerbody.** In its China Rept.: Sci.and Technol. (JPRS-CST-84-026) p 23 (See N85-20189 11-31) 1984. 85N20192

A mixed finite difference method for calculating the external and internal flow field around inlet with centerbody is presented. First, calculation by mixed finite difference method of the velocity potential equation with small disturbance in the transverse direction using Cartesian mesh, irrotational schemes, and exact body surface boundary conditions is carried out to obtain a basic field solution including the shape and location of the shock and the sonic line. Then, the full potential equation is used to improve the accuracy of the computed value of field variables. The use of multi-layer line relaxations along the radial lines is effective for inlet with centerbody, and in this case, more relaxation sweeps are carried out (with smaller relaxation factor) inside the inlet than outside. Computations were made for axisymmetric inlet with different freestream Mach numbers M (infinity) = 1.04 to approximately 1.27. Computation results show that the method is promising.

189. BENSON, T. J.; ANDERSON, B. H.: **Validation of a three-dimensional viscous analysis of axisymmetric supersonic inlet flow fields.** NASA-TM-83058 E-1523 NAS 1.15:83058 1983. 83N17538

A three-dimensional viscous marching analysis for supersonic inlets was developed. To verify this analysis

several benchmark axisymmetric test configurations were studied and are compared to experimental data. Detailed two-dimensional results for shock-boundary layer interactions are presented for flows with and without boundary layer bleed. Three dimensional calculations of a cone at angle of attack and a full inlet at attack are also discussed and evaluated. Results of the calculations demonstrate the code's ability to predict complex flow fields and establish guidelines for future calculations using similar codes.

190. WASSERBAUER, J. F.; CUBBINSON, R. W.; TREFNEY, C. J.: **Low Speed Performance of a supersonic axisymmetric mixed compression inlet with auxiliary inlets**. NASA-TM-83435 E-1730 NAS 1.15:83435 1983. 83N27992

The aerodynamic performance of a representative supersonic cruise inlet was investigated using a fan simulator coupled to the inlet to provide characteristic noise signatures and to pump the inlet flow. Data were obtained at Mach numbers from 0 to 0.2 for the inlet equipped with an auxiliary inlet system that provided 20 to 40 percent of the fan flow. Results show that inlet performance improved when the inlet bleed systems were sealed; when the freestream Mach number was increased; and when the auxiliary inlets were opened. The inlet flow could not be choked by either centerbody translation or by increasing the fan speed when the 40 percent auxiliary inlet was incorporated.

191. WASSERBAUER, J. F.; CUBBISON, R. W.; TREFNY, C. J.: **Low speed performance of a supersonic axisymmetric mixed compression inlet with auxiliary inlets**. AIAA PAPER 83-1414 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 31 p. 1983. 83A45516

The aerodynamic performance of a representative supersonic cruise inlet was investigated using a fan simulator coupled to the inlet to provide characteristic noise signatures and to pump the inlet flow. Data were obtained at Mach numbers from 0 to 0.2 for the inlet equipped with an auxiliary inlet system that provided 20 to 40 percent of the fan flow. Results show that inlet performance improved when the inlet bleed systems were sealed; when the freestream Mach number was increased; and when the auxiliary inlets were opened. The inlet flow could not be choked by either centerbody translation or by increasing the fan speed when the 40 percent auxiliary inlet was incorporated. Previously announced in STAR as 83N27992.

192. DEESE, J. E.; AGARWAL, R. K.: **Calculation of axisymmetric inlet flow field using the Euler equations**. AIAA PAPER 83-1853 American Institute of Aeronautics and Astronautics, Applied Aerodynamics Conference, Danvers, MA, July 13-15, 1983. 7 p. Research supported by the McDonnell Douglas Independent Research and Development Program. 1983. 83A38681

An existing two-dimensional Euler solver has been modified to treat axisymmetric flow. Solutions for transonic flow fields about engine inlet nacelles with and without hubs are obtained by combining the Euler solver with a general grid-generation scheme. The results are compared with experimental data and transonic potential equation solutions. For the cases examined, involving subsonic flow or flow with weak shocks, the Euler method gives results which compare well with the experimental data and potential equation solutions.

193. IVES, D. C.: **Supercritical inlet design**. AIAA PAPER 83-1866. American Institute of Aeronautics and Astronautics, Applied Aerodynamics Conference, Danvers, MA, July 13-15, 1983. 9 p. 1983. 83A38693

A semi-inverse method has been developed to design supercritical axisymmetric inlets having specified pressure distributions. This method has its roots in a number of current airfoil design techniques, and this paper extends and unifies some of these seemingly diverse approaches. The present design method is a direct method as far as the flow solver is concerned since it uses a flow solver only to evaluate pressure distributions corresponding to specified geometries. The present design method is an inverse method based on conformal mapping from an overall viewpoint, however, so the description 'semi-inverse design' is used. This semi-inverse capability prevents premature obsolescence by adapting easily to new flow analyses as they are developed. The method has good accuracy (typically 1/10 percent) except for a small (1 percent) error following a rapid expansion or compression. The stability of this method is moderate, requiring some underrelaxation in the early stages of a design, but no smoothing has been necessary. The capability of this method is illustrated by the design of a segment of an inlet holding the remainder of the inlet fixed, and by the design of an axisymmetric supercritical natural laminar flow inlet.

194. VINOGRADOV, V. A.; DUGANOV, V. V.; STEPANOV, V. A.: **Application of numerical methods to the calculation of the characteristics of supersonic and hypersonic jet-engine air intakes**. TsAGI, Uchenye

Zapiski (ISSN 0321-3429), vol. 13, no. 2, 1982, p. 62-68. In Russian. 1982. 83A37532

The numerical method of Vinogradov and Duganov (1979) was used to analyze a mixed-compression axisymmetric intake (freestream Mach = 2-3.5) and a plane intake (freestream Mach = 6), with allowance for the boundary layer under the assumption of nonseparated flow. Good agreement between numerical and experimental results is shown for the local flow parameters p and M as well as for the integral characteristics of the intakes nu, f, and Cx.

195. MILESHIN, V. I.; TILLIAEVA, N. I.: **Comparison of computational and experimental data concerning flow past axisymmetric air intakes in regimes with an expelled shock wave.** TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 13, no. 2, 1982, p. 135-141. In Russian. 1982.83A37541

Tilliaev's (1979) method for calculating the supersonic flow of an inviscid non-heat-conducting gas past plane air intakes in regimes with an expelled shock wave is extended to the case of axisymmetric flow and is improved with regard to its speed and accuracy. A boundary condition at the intake outlet is proposed which assures the establishment of steady flow regimes in a minimum time. The proposed method is used to calculate flow past models of axisymmetric air intakes for three values of freestream Mach number (2.1.4, 2.48, and 2.9) and different values of the discharge coefficient. A comparison between calculations and experimental results is made.

196. SYBERG, J.; TURNER, L.: **Supersonic test of a mixed-compression axisymmetric inlet at angles of incidence.** NASA-CR-165686 1981. 81X10213 <u>US GOV AGENCIES AND CONTRACTORS</u>

Data obtained during wind tunnel testing of a large scale, axisymmetric, supersonic inlet and an analysis of the inlet performance during operational angle of incidence are presented. Duct dynamic pressures were recorded to support the development of advanced inlet control systems. The inlet bleed system was adjusted to provide acceptable inlet performance over a wide range of Mach numbers and angles of incidence. Windward and leeward side pressure profiles were obtained by recording data at both positive and negative model angles of attack at identical test conditions. Static pressure profiles in the transverse plane were obtained by rolling the model 90 deg in the wind tunnel and repeating the test conditions. Inlet control signal data were recorded for a wide range of inlet operating conditions and data for dynamic model validation at angle of attack were obtained.

197. Evaluation of bicone and translating centerbody inlets for A M = 2.2 supersonic cruise vehicle. NASA-CR-159157 MDC-J4630 1979. 79X10154 <u>US GOV AGENCIES AND CONTRACTORS</u>

The results of an analysis of inlets for supersonic cruise vehicles is presented. The bicone inlet has the capability of a widely variable throatarea so that engine airflow demands can be satisfied throughout the transonic flight regime. The design of a bicone inlet for the 2.2 Mach MDC baseline aircraft was developed to approximately the same depth of design as the translating centerbody inlet, which was refined for the baseline.

198. PRESLEY, L.: **Angle of attack effects on axisymmetric inlet design.** In NASA Lewis Research Center Inlet Workshop, p 250-267 (See 86N72197 18-01) 1977. 86N72213

199. KONCSEK, J. L.; SYBERG, J.: **Transonic and supersonic test of a Mach 2.65 mixed-compression axisymmetric intake.**: NASA-CR-1977 1972. 72N18786

The test results describe isolated intake performance between Mach 0.95 and the cruise Mach number of 2.65 at angles of incidence from +5 to -5 deg. Maximum total pressure recoveries of over 94 percent with 10 percent distortion were recorded at the compressor face in the Mach range from 2.65 to 2.4. Typical cruise operating recovery was 91 percent with 13 percent distortion, 7 percent bleed, 5 percent corrected flow stability margin, and 2.2 deg angle-of-incidence tolerance without need for control action. In the started range below Mach 2.4, recoveries were 2 percent to 4 percent lower than the recoveries above Mach 2.4, and the distortion increased to approximately 20 percent. At Mach 0.95 the maximum measured capture flow was 99.4 percent of the theoretical choked value. The recovery was 97.1 percent with less than 10 percent distortion.

2.3 2-D INLETS

200. CAMPBELL, ANNETTE F.; BALL, WILLIAM H.; SYBERG, JAN: **Wind tunnel test of a two-dimensional external compression supersonic inlet**

model. NASA-CR-182253 NAS 1.26:182253 1989. 89X10486 US GOV AGENCIES AND CONTRACTORS

Results from an inlet test program conducted at NASA Lewis Research Center in the 10 x 10 ft Supersonic Wind Tunnel are reported. The primary objective was to evaluate the performance of a Mach 2.5 two- dimensional external compression inlet designed for high performance and high maneuverability. The test model consisted of a generic fighter- type forebody, a baseline dual-inlet assembly, and several inlet component options. Key features investigated during the test included: (1) forebody boundary layer blowing versus a boundary layer diverter; (2) mutual interference between separate subsonic diffuser ducts coupled by a common supersonic diffuser; and (3) various sideplate and cowl lip design options. Overall performance of the baseline inlet was found to be exceptionally high: an engine face total pressure recovery of 89.7 percent with 9.8 percent distortion at a total bleed flow of 5.0 percent was achieved at Mach = 2.5 and alpha and beta = 0 degrees. The shielded installation of the inlet made it highly tolerant to variations in the angle of attack, and although like all horizontal ramp inlets, the inlet was sensitive to yaw, acceptable performance was demonstrated up to + or - 4 degrees angle of yaw.

201. LEYLAND, D. C.: **Jaguar/Tornado intake design.** In VKI, Intake Aerodynamics, Volume 1, 25 p (See 89N72213 09-02) 1988. 89N16743

The assessment of aerodynamic features that led to the chosen intake configurations and particular aspects that had to be taken into account in overall design of the Jaguar and Tornado intakes are summarized. Intake sizing and profiles; pressure recovery; boundary layers; intake control; supersonic characteristics; and vortex-incidence aspects are discussed.

202. FISHER, S. A.: **Three-dimensional flow effects in a two-dimensional supersonic air intake.** (International Symposium on Air Breathing Engines, 7th, Beijing, People's Republic of China, September 2-6, 1985, Proceedings, p. 118-124) Journal of Propulsion and Power (ISSN 0748-4658), vol. 2, Nov.-Dec. 1986, p. 546-551. Previously cited in issue 02, p. 108, Accession no. 86A11612. 1986. 87A24009

203. SANZ, A.: **On the two-dimensional theory of incompressible flow over inlets.** ASME, Transactions, Journal of Applied Mechanics (ISSN 0021-8936), vol. 53, Dec. 1986, p. 947-951. 1986. 87A23221

The linearized solution for the two-dimensional flow over an inlet of general form is derived assuming incompressible potential flow. The method, which is applicable to two-dimensional, almost-straight inlets, consists mainly of three steps: (1) finding a suitable conformal mapping which transforms the 'skeleton' of the intake in the real axis; (2) identifying and taking into account the singularities of the transformation which occur at the inlet tip and at the infinity inside the inlet; and (3) calculating the velocity at the mapped plane. Design criteria for ideal inlets are obtained and the derived expression is validated by checking against the exact solution of a simple problem obtained by a Schwarz-Christoffel transformation. A comparison is made with the results of Huang (1982), showing a 20 percent difference although both results match for alpha = 1 as expected.

204. DUGANOV, V. V.; ZAKHAROV, N. N.; IVANOV, O. K.: **Experimental study of supersonic flow around a single-stage wedge with cheeks at sideslip angles.** Aviatsionnaia Tekhnika (ISSN 0579-2975), no. 1, 1986, p. 107-110. In Russian. 1986. 86A43404

Experimental results are presented concerning flow around a single-stage wedge with side cheeks (a configuration typical for two-dimensional supersonic intakes) at sideslip angles of 0, 5, and 10 deg. Experiments were carried out in a wind tunnel at a Mach number of 2.1, a Reynolds number of 10 to the 8th (for a characteristic dimension of 1 m), and a stagnation temperature of 288 K. The pressure distributions are examined, and the shock-wave configuration generated in the flow is discussed.

205. FISHER, S. A.: **Three-dimensional flow effects in a two-dimensional air intake with mixed supersonic compression.**: International Symposium on Air Breathing Engines, 7th, Beijing, People's Republic of China, September 2-6, 1985, Proceedings (86A11601 02-07). NewYork, AIAA, 1985, p. 118-124. 1985. 86A11612

The internal flow in a two-dimensional mixed compression intake having focussed internal compression was examined experimentally at its design Mach number of 3.05, using pressure instrumentation and flow visualization. A pair of streamwise vortices was identified, which apparently resulted from interaction of the sidewall boundary layers with the internal shock system and which, depending on detailed geometry, could dominate the flow in the subsonic diffuser. It is argued that similar flows could exist in a variety of intakes

designed for supersonic flight, with implications for both turbine and ram compression engine applications.

206. LIOU, M.-S.; HANKEY, W. L.; MACE, J. L.: **Numerical simulation of a supercritical inlet flow**. AIAA PAPER 85-1214 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 21st, Monterey, CA, July 8-10, 1985. 8 p. 1985. 85A39658

The Reynolds-averaged, unsteady Navier-Stokes equations were solved numerically to predict flow-fields in a two-dimensional supersonic inlet. First, a brief description of numerical procedures, as well as boundary conditions is given. The discussion of calculated results follows. A flow at supercritical conditions was calculated and found to be unsteady. Hence, detailed spectral information for the computed data is given and the boundary-layer parameters, e.g., skin friction coefficients, are shown. Several physically interesting phenomena are discussed. The distribution of the entropy change indicating the performance of the inlet under the chosen set of conditions is given also.

207. GURYLEV, V. G.; KORCHINSKAIA, M. IU.; CHEVAGIN, A. F.: **Flow structure and maximum static pressures at the inlet and in the throat of plane air intakes at high supersonic velocities**. TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 16, no. 1, 1985, p. 46-53. In Russian. 1985. 86A48756

The interaction between an oblique shock wave reflected from the inlet edge of an intake and the boundary layer at the braking wedge is investigated for Mach 2-5 and Reynolds numbers of (5-10) x 10 to the 6th. The limiting flow conditions associated with maximum local static pressures are determined. The effect of boundary layer suction on the flow structure in the intake throat and on the level of maximum static pressures is examined.

208. BIRINGEN, S.: **Numerical simulation of two-dimensional inlet flow fields**. Journal of Aircraft (ISSN 0021-8669), vol. 21, April 1984, p.244-249. 1984. 84A26954

Inlet flow fields for airbreathing missiles are calculated by a two-dimensional computational method. A supersonic freestream is assumed to allow the forebody calculation to be uncoupled from the inlet calculation. The inlet calculation employs an implicit, time-marching, finite difference procedure to solve the Euler equations formulated in body-fitted coordinates. The method can be used for a flow field with both subsonic and supersonic regions and is found to converge rapidly for supercritical inlet operation. For subcritical inlet operation, however, convergence to steady state is slow.

209. BOSNIAKOV, S. M.; BYKOVA, S. A.; REMEEV, N. KH.: **A study of the spatial flow and aerodynamic characteristics of two-dimensional intakes with various inlet shapes and lateral surface dimensions**. TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 14, no. 3, 1983, p. 107-113. In Russian. 84A45745

The characteristics of a schematic two-dimensional intake in supersonic flow (free-stream Mach, 2-4) are investigated analytically and experimentally. Versions with various types of lateral surfaces and various ratios of the inlet sides are considered. It is shown that the three-dimensional nature of flow depends on the above parameters and that it has a significant effect on the intake characteristics.

210. TINDELL, R. H.; HOELZER, C. A.; ALEXANDER, D.: **F-14 inlet development experience**. ASME PAPER 82-GT-5. American Society of Mechanical Engineers, International Gas Turbine Conference and Exhibit, 27th, London, England, Apr. 18-22, 1982, 11 p. 1982. 82A35278

The inlet control system of the F-14 fighter, which has demonstrated in-flight compatibility with the advanced F401-PW-400 and GE-F-101X engines, as well as the TF30 engine, is based on a simple concept that minimizes maintenance and maximizes reliability. The potential benefits of inlet and engine control integration are presently under study. The primary function of the air inlet control system is to position the three variable ramps in each inlet to some preset schedule of angles, so that ramp position is exclusively a function of Mach number. To achieve low total pressure distortion for static operation, total pressure recovery was intentionally lowered to minimize differences between average and minimum pressures. Analytical estimates of aircraft forebody effects on the inlet flow field, using a three-dimensional inviscid supersonic flow field code, are found to be close to wind tunnel test results. Suggestions are made in light of study determinations for more advanced inlet designs.

211. BOSNYAKOV, S. M.; REMEYEV, N. K.: **Study of the three-dimensional flow around the two-dimensional inlet with the latest jaws of the supersonic flow of gas**. In its Sci. Notes of TsAGI (FTD-ID(RS)T-

0801-81) p 90-107 (See 82X73015 09-01) 1981. 82X73020 US GOV AGENCIES

212. BIRINGEN, S.; MCMILLAN, O. J.: **Calculation of two-dimensional inlet flow fields by an implicit method including viscous effects.**: User's manual. NASA-CR-3412 NEAR-TR-231 1981. 81N23027

Inlet flow fields for airbreathing missiles are calculated by the adaptation of a two dimensional computational method developed for the flow around airfoils. A supersonic free stream is assumed to allow the forebody calculation to be uncoupled from the inlet calculation. The inlet calculation employs an implicit, time marching finite difference procedure to solve the thin layer Navier-Stokes equations formulated in body fitted coordinates. The mathematical formulation of the problem and the solution algorithm are given. Numerical stability and accuracy as well as the initial and boundary conditions used are discussed. Instructions for program use and operation along with the overall program logic are also given.

213. BIRINGEN, S.; MCMILLAN, O. J.: **A numerical simulation of two-dimensional inlet flow fields.** AIAA PAPER 81-0187. American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 19th, St. Louis, MO, Jan. 12-15, 1981, 9 p. 1981. 81A40318

Inlet flow fields for airbreathing missiles are calculated by the adaptation of a two-dimensional computational method developed for the flow around airfoils. A supersonic free stream is assumed to allow the forebody calculation to be uncoupled from the inlet calculation. The inlet calculation employs an implicit, time-marching finite-difference procedure to solve the thin-layer Navier-Stokes equations formulated in body-fitted coordinates. Because the method can be used for a flow field with both subsonic and supersonic regions, it is applicable to subcritical as well as supercritical inlet operation.

214. BIRINGEN, S.; MCMILLAN, O. J.: **Calculation of two-dimensional inlet flow fields by an implicit method including viscous effects.**: Program documentation and test case. NASA-CR-3414 NEAR-TR-233 1981. 81N26077

The source listing of a computer code for calculating the flow fields in a supersonic free stream is given. The application of this code to an inlet on an airbreathing missile is also presented.

215. BALL, W. H.; SYBERG, J.; SURBER, L. E.: **Experimental investigation of a high-aspect-ratio supersonic inlet.** AIAA PAPER 81-1397 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 13 p. 1981. 81A42187

Tests were conducted in the AEDC 16S wind tunnel to measure the internal aerodynamic performance of a 0.27-scale high aspect-ratio, external compression, two-dimensional, side-mounted inlet. The inlet incorporated throat slot and distributed bleed, large diffuser offset, and variable ramps. Configuration variables included sideplate cutback, diffuser turning vanes, throat rakes, and forebody. Testing was accomplished from Mach 1.60 to 2.20. Compressor face and throat total pressure profiles, compressor turbulence levels, and inlet surface static pressures were recorded to determine diffuser and overall inlet performance. Test results indicate the high-aspect-ratio inlet is a viable design option for future supersonic aircraft.

216. STOCKS, C. P.; BISSINGER, N. C.: **The design and development of the Tornado engine air intake.** AGARD CP-301, p. 10.1 - 10.21. 1981. 82N13074

The design and development of the Tornado aircraft supersonic intake is described. Critical aerodynamic design areas are outlined with special emphasis on compatibility. The intakes were designed to satisfy the conflicting requirements of greater than Mach 2 operation and a very wide incidence operating envelope at subsonic speeds. The problem of design loads is reviewed as well as the theory and operation of the automatic control system. Propulsion system behavior in flight and some examples of intake-airframe interaction are described.

217. BIRINGEN, S. H.; MCMILLAN, O. J.: **Calculation of two-dimensional inlet flow fields in a supersonic free stream by an implicit marching code with nonorthogonal mesh generation: User's manual.**: NASA-CR-3222 NEAR-TR-193 1980. 80N15048

An implicit, shock-capturing finite-difference code which is used to calculate two-dimensional inlet flow fields in a supersonic free stream is explained. The Euler equations are subjected to general nonorthogonal transformation and a body-fitted coordinate system is employed. The mathematical formulation of the problem is given along with the numerical algorithm. Initial and boundary conditions, numerical stability, program limitations, and accuracy is discussed. An overall program logic as well

as instructions for program use and operation are also furnished.

218. KNIGHT, D. D.: **Calculation of high speed inlet flows using the Navier-Stokes equations. Volume 1: Description of results.** AD-A084789 AFFDL-TR-79-3138-VOL-1 1980. 80N28318

A set of computer programs has been developed to calculate the flow field in two dimensional mixed-compression high speed inlets. The full mean compressible Navier-Stokes equations are utilized, with turbulence represented by an algebraic eddy viscosity model which incorporates a relaxation correction. A curvilinear body-oriented coordinate system is employed to allow handling of arbitrary inlet contours. Boundary layer bleed is incorporated. The numerical algorithm of MacCormack is employed to solve the Navier-Stokes equations. A variety of techniques are incorporated to improve code efficiency, including time-splitting of the finite-difference operators, automatic mesh-splitting, and a separate algorithm for the treatment of the viscous sublayer portion of the turbulent boundary layers. The numerical codes have been successfully applied to the calculation of a variety of flows including shock-boundary layer interaction on a flat plate (including both unseparated and separated cases), and three different simulated high speed inlet configurations. In all cases, good agreement was obtained with the experimental data.

219. KNIGHT, D. D.: **Calculation of high speed inlet flows using the Navier-Stokes equations. volume 2: User's and programmer's guide**.: AD-A084790 AFFDL-TR-79-3138-VOL-2 1980. 80N28319

A series of four computer programs used to compute the flow field within a two dimensional, mixed compression, high speed, aircraft inlet are documented. A brief description is presented of the physical problem and the mathematical model. The numerical methods are discussed and the limitations of the approach are indicated. A brief summary of the four programs is presented together with the general sequence of application. The coordinate system programs are discussed in detail with emphasis on the pertinent criteria for successful implementation. The details of the Navier-Stokes code employed for solution of the inlet flow field are presented. In addition, the details of a simple utility program used to interpolate flow filed data are discussed.

220. KNIGHT, D. D.: **Improved numerical simulation of high speed inlets using the Navier-Stokes equations.** AIAA PAPER 80-0383 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 17 p. 1980. 80A18340

An improved numerical algorithm has been developed to calculate the flow field in two-dimensional mixed-compression high speed inlets using the Navier-Stokes equations. The explicit finite-difference algorithm of MacCormack is utilized, together with a modified treatment of the viscous sublayer and transition wall region of the turbulent boundary layers. A variety of flows have been considered, including shock-turbulent boundary layer interaction on a flat plate and three different configurations of a simulated high speed inlet. The computed results compare favorably with the experimental data.

221. BIRINGEN, S. H.; MCMILLAN, O. J.: **Calculation of two-dimensional inlet flow fields in a supersonic free stream: Program documentation and test cases**. NASA-CR-3221 NEAR-TR-195 1980. 80N17029

The use of a computer code for the calculation of two dimensional inlet flow fields in a supersonic free stream and a nonorthogonal mesh-generation code are illustrated by specific examples. Input, output, and program operation and use are given and explained for the case of supercritical inlet operation at a subdesign Mach number (M Mach free stream = 2.09) for an isentropic-compression, drooped-cowl inlet. Source listings of the computer codes are also provided.

222. TILLIAEVA, N. I.: **Numerical method for calculating supersonic flow past a plane air intake with detached shock wave.** TsAGI, Uchenye Zapiski, vol. 10, no. 2, 1979, p. 30-40. In Russian. 1979. 80A27148

An ideal gas model is used to develop an algorithm for calculating supersonic flow past an intake with detached shock wave. A difference scheme for calculating the flow is described, and some numerical results for different freestream Mach numbers are presented. Finally, approximate methods for determining the integral characteristics of the intake are discussed.

2.4 EXTERNAL COMPRESSION

223. CAMPBELL, ANNETTE F.; BALL, WILLIAM H.; SYBERG, JAN: **Wind tunnel test of a two-dimensional external compression supersonic inlet model.** NASA-CR-182253 NAS 1.26:182253 1989. 89X10486 US GOV AGENCIES AND CONTRACTORS

Results from an inlet test program conducted at NASA Lewis Research Center in the 10 x 10 ft Supersonic Wind Tunnel are reported. The primary objective was to evaluate the performance of a Mach 2.5 two- dimensional external compression inlet designed for high performance and high maneuverability. The test model consisted of a generic fighter-type forebody, a baseline dual-inlet assembly, and several inlet component options. Key features investigated during the test included: (1) forebody boundary layer blowing versus a boundary layer diverter; (2) mutual interference between separate subsonic diffuser ducts coupled by a common supersonic diffuser; and (3) various sideplate and cowl lip design options. Overall performance of the baseline inlet was found to be exceptionally high: an engine face total pressure recovery of 89.7 percent with 9.8 percent distortion at a total bleed flow of 5.0 percent was achieved at Mach = 2.5 and alpha and beta = 0 degrees. The shielded installation of the inlet made it highly tolerant to variations in the angle of attack, and although like all horizontal ramp inlets, the inlet was sensitive to yaw, acceptable performance was demonstrated up to + or - 4 degrees angle of yaw.

224. BENSON, THOMAS J.: **CFD application to supersonic/hypersonic inlet airframe integration.** In VKI, Intake Aerodynamics, Volume 2, 62 p (See 89N16748 09-02) 1988. 89N16754

Supersonic external compression inlets are introduced, and the computational fluid dynamics (CFD) codes and tests needed to study flow associated with these inlets are outlined. Normal shock wave turbulent boundary layer interaction is discussed. Boundary layer control is considered. Glancing sidewall shock interaction is treated. The CFD validation of hypersonic inlet configurations is explained. Scramjet inlet modules are shown.

225. HOWLETT, D. G.; HUNTER, L. G.: **A study of a supersonic axisymmetric spiked inlet at angle of attack using the Navier-Stokes equations.** AIAA PAPER 86-0308 AIAA, Aerospace Sciences Meeting, 24th, Reno, NV, Jan. 6-9, 1986. 12 p. 1986. 86A22691

Numerical solutions of the 3-D, unsteady, compressible Navier-Stokes equations were obtained for the flow field about an external compression axisymmetric spike inlet at angle-of-attack for a Mach number of 2.0. MacCormack's explicit finite difference algorithm was utilized to obtain the numerical solution. The computational results were able to predict the spike-centerbody and internal cowl pressure for angles-of-attack up to 8 degrees. In addition, the inlet overpressure on the leeward side was also predicted which is a major contribution to inlet unstart. Numerical results are given in terms of Mach number, static pressure, and total pressure contours. Static pressure and pressure recovery comparisons with experimental data are also given.

226. BUSH, R. H.: **External compression inlet predictions using an implicit, upwind, multiple zone approach.** AIAA PAPER 85-1521: Computational Fluid Dynamics Conference, 7th, Cincinnati, OH, July 15-17, 1985, Technical Papers (85A40926 19-34). New York, AIAA, 1985, p. 438-447. 85A40966

The present zonal methodology for existing time-dependent numerical codes is based on boundary conditions that are currently popular in treatments of inflow and outflow boundaries, and, since it may be characterized as a modification of the boundary conditions with a scheme for communicating between zones, it is easily incorporated into numerical codes. The methodology can be extended to three dimensions, and provides a straight forward means for the computation of complex geometric configurations by subdividing the computational domain into a series of simple zones. The methodology is used to compute the performance of an external compression inlet, for which it yielded detailed data on such inherently two-dimensional phenomena as boundary layer behavior and cowl lip flows.

227. KAPOOR, K.; PAI, T. G.: **Experimental studies on subcritical intakes flows.**: International Council of the Aeronautical Sciences, Congress, 14th, Toulouse, France, September 9-14, 1984, Proceedings. Volume 2 (84A44926 22-01). New York, American Institute of Aeronautics and Astronautics, 1984, p. 1024-1029. Research supported by the Ministry of Defence of India. 1984. 84A45040

An experimental study on two-dimensional external compression supersonic air intakes, leading to development of subcritical flow models, forms the objective of present paper. Intake models incorporating variable geometry feature and a mass flow measuring and monitoring unit have been tested for Mach number range

of 1.6 to 2.2. Based on the experimental data, a subcritical flow model correlating intake geometry, shock stand-off distance and free stream Mach number has been developed. Additive drag and stable range of intake operation using flow model evolved has been compared with the corresponding values reported in the literature and those which were obtained during current experiments. Two types of flow instabilities have also been observed.

228. HE, Z.; ZHANG, S.: **Buzz in axisymmetric supersonic inlet and its control**. Acta Aeronautica et Astronautica Sinica, vol. 4, June 1983, p. 73-82. In Chinese, with abstract in English. 1983. 84A12042

Static pressure fluctuations at the cone surface in the throat of an axisymmetric external compression inlet were examined to detect the cause of buzz at the inlet and its control in supersonic conditions. The flow was confined to Mach 1.97 for the tests, which also covered angles of attack of 0 and 12 deg. A sharp pressure fluctuation was found, along with the buzz, when the bow shock separated from the cowl lip at 0 deg. The buzz displayed a characteristic frequency of 43.75 Hz. A buzz frequency of 18.75 Hz was obtained at 12 deg as the bow shock at the lee side of the cone vibrated abruptly and with large amplitude. A specific mass flow permitted through the inlet door eliminated the buzz, stabilized the bow shock, and lowered the amplitude of the pressure fluctuation.

229. ZHANG, K.; YU, S.; PENG, C.: **Effect of a shear layer on stability of an axisymmetric external compression air intake**. Acta Aeronautica et Astronautica Sinica, vol. 4, Sept. 1983, p. 56-62. In Chinese, with abstract in English. 1983. 84A23908

The influence of shear layers of various strengths on the stability of an axisymmetric compression supersonic air intake is studied. Strength is defined as the ratio of total pressure difference between the two sides of a shear layer to the total pressure of the incoming flow. Six central bodies with different cone angles were used to produce shear layers with strengths ranging from 5 to 11 percent of the total pressure of upstream flow inside a free stream wind tunnel with a fixed Mach number of 1.72. Shear layers with less than 10 percent strength were strong enough to cause separation of the boundary layer from the inside surface of the cowl. Shear layers of strength less than 11 percent failed to induce buzz in the axisymmetric intake. The influence of a shear layer depended on its distance from the lip of the cowl, and was most noticeable at a distance of 10-18 percent of the cowl radius.

230. SURBER, L.; SYBERG, J.; KONCSEK, J.: **Performance of highly integrated inlets for supersonic aircraft**. In AGARD Aerodyn. of Power Plant Installation, 12 p (See 82N13065 04-01) 1981. 82N13066

Performance data obtained on several subsonic diffusers applicable to advanced supersonic tactical aircraft configurations were used to select a forebody-inlet model for proof-of-concept wind tunnel performance evaluation. Three of the diffusers were designed for high aspect ratio inlets having throat aspect ratios greater than seven. A fourth design incorporated a low aspect ratio inlet. Two of the high aspect ratio diffusers and the low aspect ratio diffuser incorporated duct bends typical of inlets substantially offset from the engine centerline. Preliminary tests of the high aspect of ratio diffuser produced high total pressure recovery coupled with relatively low flow distortion. Furthermore, the use of longitudinal vanes in one high aspect ratio diffuser provided reductions in engine face flow distortion with very little performance degradation. Proof-of-concept tests further investigated the performance of a high aspect ratio, side-mounted external compression supersonic inlet. Tests were performed in a 16-foot supersonic propulsion wind tunnel at Mach numbers of 1.6 to 2.2 over a -5 to 12 deg angle of attack range and sideslip angles from -8 to +8 deg. The results of these tests support the use of high aspect ratio inlets with sharp duct bends as a viable design option in future supersonic aircraft designs.

231. TINDELL, R. H.: **Inlet drag and stability considerations for M/0/ = 2.00 design**. AIAA PAPER 80-1105 AIAA, SAE, and ASME, Joint Propulsion Conference, 16th, Hartford, Conn., June 30-July 2, 1980, AIAA 12 p. 1980. 80A38916

The results of an experimental study to evaluate the drag and low flow stability range of several isolated inlet models are reviewed. Performance comparisons of a rectangular and semiconical model are made and effects of the external compression system, ranging from normal shock to three-shock designs, are discussed and compared to simple theoretical calculations. The study also examines the effectiveness of several means for improving low flow stability, and compares their drag characteristics. An inlet drag coefficient which defines the total installation penalty more completely is introduced.

232. BANGERT, L. H.; SANTMAN, D. M.; HORIE, G.; MILLER, L. D.: **Effects on inlet technology on cruise speed selection**. In NASA Langley Research Center Supersonic Cruise Res., 1979, Pt. 1 p 391-411 (See 81N17981 09-01) 1980. 81N17998

The impact of cruise speed on technology level for certain aircraft components is examined. External-compression inlets were compared with mixed compression, self starting inlets at cruise Mach numbers of 2.0 and 2.3. Inlet engine combinations that provided the greatest aircraft range were identified. Results show that increased transonic to cruise corrected air flow ratio gives decreased range for missions dominated by supersonic cruise. It is also found important that inlets be designed to minimize spillage drag at subsonic cruise, because of the need for efficient performance for overland operations. The external compression inlet emerged as the probable first choice at Mach 2.0, while the self starting inlet was the probable first choice at Mach 2.3. Airframe propulsion system interference effects were significant, and further study is needed to assess the existing design methods and to develop improvements.

233. KISER, C. E.; **Results of the B-1 .07 scale external compression inlet drag model wind tunnel test.**: Rep. NA-74-159, B-1 Div., Rockwell International, Dec. 1974. 78X76901

234. HAAGENSON, W. R.; RANDALL, L. M.: **Inlet development for the B-1 strategic bomber**. AIAA PAPER 74-1064 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 10th, San Diego, Calif., Oct. 21-23, 1974, AIAA 9 p. 1974. 75A10258
The B-1 inlet was originally a mixed compression design, but later changed to an external compression inlet (ECI). All major problems encountered in adapting the ECI to the B-1 were solved during the first wind tunnel development test. Aerodynamic characteristics of the inlet and, particularly, the characteristics of certain inlet control parameters are associated with the underwing location of the nacelle. Inlet distortion and inlet/engine compatibility have been carefully audited throughout the B-1 program. A demonstration of inlet/engine compatibility before first flight was provided by wind tunnel tests of a full-scale inlet/engine model at Arnold Engineering Development Center.

235. BUSH, R. H.: **External compression inlet predictions using an implicit, upwind, multiple zone approach.** AIAA PAPER 85-1521 IN: Computational Fluid Dynamics Conference, 7th, Cincinnati, OH, July 15-17, 1985, Technical Papers (85A40926 19-34). New York, AIAA, 1985, p. 438-447. 1985. 85A40966

The present zonal methodology for existing time-dependent numerical codes is based on boundary conditions that are currently popular in treatments of inflow and outflow boundaries, and, since it may be characterized as a modification of the boundary conditions with a scheme for communicating between zones, it is easily incorporated into numerical codes. The methodology can be extended to three dimensions, and provides a straightforward means for the computation of complex geometric configurations by subdividing the computational domain into a series of simple zones. The methodology is used to compute the performance of an external compression inlet, for which it yielded detailed data on such inherently two-dimensional phenomena as boundary layer behavior and cowl lip flows.

2.5 INTERNAL COMPRESSION

236. BION, J. R.: **Characteristics of air intake flow fields and evaluation of the loss of compression surge margin due to flowfield distortions in the compressor inlet plane.**: ONERA, TP NO. 1986-98 (ICAS, Congress, 15th, London, England, Sept. 7-12, 1986) ONERA, TP, no. 1986-98, 1986, 10 p. 87A21024

This report contains information on flow distortion, inlet flow, internal compression inlets, surges, ducted flow, engine tests, flow visualization, pressure measurement, and wind tunnel tests.

2.6 MIXED COMPRESSION

237. CHYU, W. J.; KAWAMURA, T.; BENCZE, D. P.: **Navier-Stokes solutions for mixed compression axisymmetric inlet flow with terminal shock.** (AIAA, Aerospace Sciences Meeting, 25th, Reno, NV, Jan. 12-15, 1987, AIAA Paper 87-0160) Journal of Propulsion and Power (ISSN 0748-4658), vol. 5, Jan.-Feb. 1989, p. 4, 5. Abridged. Previously cited in issue 09, p. 1191, Accession no. 87A24932. 1989. 89A22276

238. KAWAMURA, T.; CHYU, W. J.; BENCZE, D. P.: **Numerical simulation of three-dimensional supersonic inlet flow fields.** AIAA PAPER 87-0160. AIAA, Aerospace Sciences Meeting, 25th, Reno, NV, Jan. 12-15, 1987. 13 p. 1987. 87A24932

Supersonic inlet flows with mixed external-internal compressions of an axisymmetric inlet model were computed using a combined implicit-explicit (Beam-

Warming-Steger/MacCormack) method for solving the three-dimensional unsteady, compressible Navier-Stokes equations in conservation form. Numerical calculations were made of various flows typically found in supersonic inlets such as shock-wave intersections, flow spillage around the cowl lip, shock-wave/boundary-layer interactions, control of shock-induced flow separation by means of boundary layer bleed, internal normal (terminal) shocks, and the effects of flow incidence. Computed results were compared with available wind tunnel data.

239. KAWAMURA, T.; CHYU, W. J.; BENCZE, D. P.: **Numerical simulation of three-dimensional supersonic inlet flow fields**. AIAA PAPER 87-0160. AIAA, Aerospace Sciences Meeting, 25th, Reno, NV, Jan. 12-15, 1987. 13 p. 1987. 87A24932

Supersonic inlet flows with mixed external-internal compressions of an axisymmetric inlet model were computed using a combined implicit-explicit (Beam-Warming-Steger/MacCormack) method for solving the three-dimensional unsteady, compressible Navier-Stokes equations in conservation form. Numerical calculations were made of various flows typically found in supersonic inlets such as shock-wave intersections, flow spillage around the cowl lip, shock-wave/boundary-layer interactions, control of shock-induced flow separation by means of boundary layer bleed, internal normal (terminal) shocks, and the effects of flow incidence. Computed results were compared with available wind tunnel data.

240. FISHER, S. A.: **Three-dimensional flow effects in a two-dimensional air intake with mixed supersonic compression.**: International Symposium on Air Breathing Engines, 7th, Beijing, People's Republic of China, September 2-6, 1985, Proceedings (86A11601 02-07). NewYork, AIAA, 1985, p. 118-124. 1985. 86A11612

The internal flow in a two-dimensional mixed compression intake having focussed internal compression was examined experimentally at its design Mach number of 3.05, using pressure instrumentation and flow visualization. A pair of streamwise vortices was identified, which apparently resulted from interaction of the sidewall boundary layers with the internal shock system and which, depending on detailed geometry, could dominate the flow in the subsonic diffuser. It is argued that similar flows could exist in a variety of intakes designed for supersonic flight, with implications for both turbine and ram compression engine applications.

241. POWELL, A. G.; FRASCA, R. L.; PELLINO, A. G.: **Technology study for advanced supersonic cruise vehicles inlet technology.** NASA-CR-172602 NAS 1.25:172602 1985. 85X10356 US GOV AGENCIES AND CONTRACTORS

Low-speed tests were conducted in the NASA LeRC 9x15 wind tunnel at Mach numbers of 0, 0.1, and 0.2 to measure the aerodynamic and acoustic characteristics of an axisymmetric mixed compression supersonic inlet with variable cowl slot. The inlet model which was powered by the JT8D single-stage fan simulator consisted of the NASA P-inlet centerbody and two cowls. The performance cowl was tested over a range of flows, cowl slot openings, centerbody positions and angles of attack. Total pressure recovery, steady-state and dynamic distortions and selected rake data are presented. The acoustic cowl was tested to determine the acoustic effectiveness of the design absorptive linings. Data were recorded with the variable cowl slot in the full open and closed positions to simulate takeoff and landing operations. Noise measurements were made on an arc around the inlet to obtain directivity information and on various internal surfaces for diagnostic information.

242. BECK, W. E.; JR.; BOCHARY, E.: **Aerodynamic and acoustic performance of an axisymmetric supersonic inlet with auxiliary inlets operating at low speed.** NASA-CR-177962 NAS 1.26:177962 LR-30885 1985. 85X10396 US GOV AGENCIES AND CONTRACTORS

A 1/3 scale model test program was conducted in the NASA LeRC 9x15 ft. Anechoic Wind Tunnel to investigate the low speed aerodynamic and acoustic performance characteristics of a mixed compression, axisymmetric supersonic inlet operating with auxiliary inlets. A JT80 fan simulator was used to pump inlet airflow and to provide engine noise signatures. The model configuration was varied to simulate inlet centerbody spike positions of the full-scale design. Configuration variations also included three auxiliary door shapes with differing auxiliary duct area distributions and two door positions that varied throat area. Test were conducted at tunnel (freestream) Mach numbers of 0, 0.1, and 0.2, and for a range of corrected fan speeds that simulated takeoff and approach conditions. This report presents a summary of the aerodynamic and acoustic test results. Blade passage tone (BPT) sound power levels are plotted versus corresponding inlet compressor face total pressure recovery for all configurations tested.

243. VARNER, M. O.; MARTINDALE, W. R.; PHARES, W. J.; KNEILE, K. R.; ADAMS, J. C., JR.: **Large perturbation flow field analysis and simulation for supersonic inlets.** NASA-CR-174676 NAS 1.26:174676 1984. 87N10835

An analysis technique for simulation of supersonic mixed compression inlets with large flow field perturbations is presented. The approach is based upon a quasi-one-dimensional inviscid unsteady formulation which includes engineering models of unstart/restart, bleed, bypass, and geometry effects. Numerical solution of the governing time dependent equations of motion is accomplished through a shock capturing finite difference algorithm, of which five separate approaches are evaluated. Comparison with experimental supersonic wind tunnel data is presented to verify the present approach for a wide range of transient inlet flow conditions.

244. VARNER, M. O.; MARTINDALE, W. R.; PHARES, W. J.; KNEILE, K. R.; ADAMS, J. C., JR.: **Large perturbation flow field analysis and simulation for supersonic inlets.**: NASA-CR-174676 NAS 1.26:174676 1984. 87N10835

An analysis technique for simulation of supersonic mixed compression inlets with large flow field perturbations is presented. The approach is based upon a quasi-one-dimensional inviscid unsteady formulation which includes engineering models of unstart/restart, bleed, bypass, and geometry effects. Numerical solution of the governing time dependent equations of motion is accomplished through a shock capturing finite difference algorithm, of which five separate approaches are evaluated. Comparison with experimental supersonic wind tunnel data is presented to verify the present approach for a wide range of transient inlet flow conditions.

245. LIU, N.-S.; SHAMROTH, S. J.; MCDONALD, H.: **Dynamic response of shock waves in transonic diffuser and supersonic inlet - An analysis with the Navier-Stokes equations and adaptive grid.** AIAA PAPER 84-1609. American Institute of Aeronautics and Astronautics, Fluid Dynamics, Plasma Dynamics, and Lasers Conference, 17th, Snowmass, CO, June 25-27, 1984. 13 p. 1984. 84A38004

An existing method which solves the multi-dimensional ensemble-averaged compressible time-dependent Navier-Stokes equations in conjunction with mixing length turbulence model and shock capturing technique has been extended to include the shock-tracking adaptive grid systems. The numerical scheme for solving the governing equations is based on a linearized block implicit approach. The effects of grid-motion and grid-distribution on the calculated flow solutions have been studied in relative detail and this is carried out in the context of physically steady, shocked flows computed with non-stationary grids. Subsequently, the unsteady dynamics of the flows occurring in a supercritically operated transonic diffuser and a mixed compression supersonic inlet have been investigated with the adaptive grid systems by solving the Navier-Stokes equations.

246. WASSERBAUER, J. F.; CUBBINSON, R. W.; TREFNEY, C. J.: **Low Speed Performance of a supersonic axisymmetric mixed compression inlet with auxiliary inlets.** NASA-TM-83435 E-1730 NAS 1.15:83435 1983. 83N27992

The aerodynamic performance of a representative supersonic cruise inlet was investigated using a fan simulator coupled to the inlet to provide characteristic noise signatures and to pump the inlet flow. Data were obtained at Mach numbers from 0 to 0.2 for the inlet equipped with an auxiliary inlet system that provided 20 to 40 percent of the fan flow. Results show that inlet performance improved when the inlet bleed systems were sealed; when the freestream Mach number was increased; and when the auxiliary inlets were opened. The inlet flow could not be choked by either centerbody translation or by increasing the fan speed when the 40 percent auxiliary inlet was incorporated.

247. WASSERBAUER, J. F.; CUBBISON, R. W.; TREFNY, C. J.: **Low speed performance of a supersonic axisymmetric mixed compression inlet with auxiliary inlets.** AIAA PAPER 83-1414 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 31 p. 1983. 83A45516

The aerodynamic performance of a representative supersonic cruise inlet was investigated using a fan simulator coupled to the inlet to provide characteristic noise signatures and to pump the inlet flow. Data were obtained at Mach numbers from 0 to 0.2 for the inlet equipped with an auxiliary inlet system that provided 20 to 40 percent of the fan flow. Results show that inlet performance improved when the inlet bleed systems were sealed; when the freestream Mach number was increased; and when the auxiliary inlets were opened. The inlet flow could not be choked by either centerbody translation or by increasing the fan speed when the 40 percent auxiliary inlet was incorporated. Previously announced in STAR as 83N27992.

248. EVELYN, G. B.; TJONNELAND, E.; GRANDE, D. L.: **Studies of advanced supersonic technologies.** NASA-CR-166076 NAS 1.26:166076D6-51156 1983. 83X10331 US GOV AGENCIES AND CONTRACTORS

Several propulsion and structural technology advancements that offered high potential for application to future supersonic transports were investigated. Propulsion: Inlet Flow Analysis: A 3-D boundary layer program and a 3-D shock/boundary layer interaction program were completed and combined with a method of characteristics program to yield a flow analysis procedure for a supersonic diffuser of an axisymmetric inlet at angle of attack. The analysis was applied to the P-inlet operating at angle of attack to illustrate the procedure. Inlet Controls: Modern technology was applied to the controls of a mixed compression inlet to develop an integrated airframe, inlet, engine simulation, and baseline inlet and engine controllers. The inlet control was implemented in a flight type, fault tolerant, triple channel controller. Nacelle Integration Analysis: Coupling of a nonlinearized potential flow solution embedded in a general solution of a larger domain using linearized potential flow was accomplished through a four step process and was applied through a preliminary analysis of a nacelle wing combination. NACA Nozzle Test: Analysis, design and laboratory testing was accomplished to verify predicted performance and secondary flow pumping capabilities of the Naturally Aspirated Co-annular (NACA) nozzle concept. Installed Nozzle Test Program: Test techniques and procedures for evaluating various nozzle concepts and installations were investigated as to their effect on airplane performance at transonic speeds and as a means of establishing configuration preliminary drag values.

249. VADYAK, J.; HOFFMAN, J. D.: **Calculation of the flow field including boundary layer effects for supersonic mixed compression inlets at angles of attack**. NASA-CR-167941 NAS 1.26:167941 1982. 82N29269

The flow field in supersonic mixed compression aircraft inlets at angle of attack is calculated. A zonal modeling technique is employed to obtain the solution which divides the flow field into different computational regions. The computational regions consist of a supersonic core flow, boundary layer flows adjacent to both the forebody/centerbody and cowl contours, and flow in the shock wave boundary layer interaction regions. The zonal modeling analysis is described and some computational results are presented. The governing equations for the supersonic core flow form a hyperbolic system of partial differential equations. The equations for the characteristic surfaces and the compatibility equations applicable along these surfaces are derived. The characteristic surfaces are the stream surfaces, which are surfaces composed of streamlines, and the wave surfaces, which are surfaces tangent to a Mach conoid. The compatibility equations are expressed as directional derivatives along streamlines and bicharacteristics, which are the lines of tangency between a wave surface and a Mach conoid.

250. KNIGHT, D. D.: **Calculation of high speed inlet flows using the Navier-Stokes equations. volume 2: User's and programmer's guide.**: AD-A084790 AFFDL-TR-79-3138-VOL-2 1980. 80N28319

A series of four computer programs used to compute the flow field within a two dimensional, mixed compression, high speed, aircraft inlet are documented. A brief description is presented of the physical problem and the mathematical model. The numerical methods are discussed and the limitations of the approach are indicated. A brief summary of the four programs is presented together with the general sequence of application. The coordinate system programs are discussed in detail with emphasis on the pertinent criteria for successful implementation. The details of the Navier-Stokes code employed for solution of the inlet flow field are presented. In addition, the details of a simple utility program used to interpolate flow filed data are discussed.

251. KNIGHT, D. D.: **Improved numerical simulation of high speed inlets using the Navier-Stokes equations.** AIAA PAPER 80-0383 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 17 p. 1980. 80A18340

An improved numerical algorithm has been developed to calculate the flow field in two-dimensional mixed-compression high speed inlets using the Navier-Stokes equations. The explicit finite-difference algorithm of MacCormack is utilized, together with a modified treatment of the viscous sublayer and transition wall region of the turbulent boundary layers. A variety of flows have been considered, including shock-turbulent boundary layer interaction on a flat plate and three different configurations of a simulated high speed inlet. The computed results compare favorably with the experimental data.

252. BANGERT, L. H.; SANTMAN, D. M.; HORIE, G.; MILLER, L. D.: **Effects on inlet technology on cruise speed selection**. In NASA Langley Research

Center Supersonic Cruise Res., 1979, Pt. 1 p 391-411 (See 81N17981 09-01) 1980. 81N17998

The impact of cruise speed on technology level for certain aircraft components is examined. External compression inlets were compared with mixed compression, self starting inlets at cruise Mach numbers of 2.0 and 2.3. Inlet engine combinations that provided the greatest aircraft range were identified. Results show that increased transonic to cruise corrected air flow ratio gives decreased range for missions dominated by supersonic cruise. It is also found important that inlets be designed to minimize spillage drag at subsonic cruise, because of the need for efficient performance for overland operations. The external compression inlet emerged as the probable first choice at Mach 2.0, while the self starting inlet was the probable first choice at Mach 2.3. Airframe propulsion system interference effects were significant, and further study is needed to assess the existing design methods and to develop improvements.

253. SHIMABUKURO, K. M.; WELGE, H. R.; LEE, A. C.: **Inlet design studies for a Mach 2.2 advanced supersonic cruise vehicle.** AIAA PAPER 79-1814 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Meeting, New York, N.Y., Aug. 20-22, 1979,11 p. 1979. 79A51247

Various inlet-engine combinations have been studied to find a preferred inlet concept for integration with an advanced technology Mach 2.2 cruise vehicle having a cruise lift-to-drag ratio of 9.6. For the purposes of this study, the range capability for a fixed takeoff gross weight was used to assess the various inlet-engine combinations. Inlet concept selection studies are described which indicated that an axisymmetric, mixed compression inlet was preferred. This study considered four inlet and three engine cycle combinations where the engine airflow was tailored to the inlet airflow delivery capability. Detailed design studies of two mixed compression inlet types are discussed. These were a translating centerbody inlet and a collapsing centerbody bicone inlet. The aerodynamic and mechanical design of each inlet is described. These inlets were also matched to different engine cycles tailored to the inlet airflow capability. The range increments favored the bicone inlet concept primarily because of lighter weight, reduced bleed air, and greater transonic airflow/thrust capability.

254. WASSERBAUER, J. F.; GERSTENMAIER, W. H.: **Inlet-engine matching for SCAR including application of a bicone variable geometry inlet.** NASA-TM-78955 E-9706 1978. 78N27125

Airflow characteristics of variable cycle engines (VCE) designed for Mach 2.32 can have transonic airflow requirements as high as 1.6 times the cruise airflow. This is a formidable requirement for conventional, high performance, axisymmetric, translating centerbody mixed compression inlets. An alternate inlet is defined, where the second cone of a two cone center body collapses to the initial cone angle to provide a large off-design airflow capability, and incorporates modest centerbody translation to minimize spillage drag. Estimates of transonic spillage drag are competitive with those of conventional translating centerbody inlets. The inlet's cruise performance exhibits very low bleed requirements with good recovery and high angle of attack capability.

255. WASSERBAUER, J. F.; GERSTENMAIER, W. H.: **Inlet-engine matching for SCAR including application of a bicone variable geometry inlet.** AIAA PAPER 78-961 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 22 p. 1978. 78A45096

Airflow characteristics of variable cycle engines (VCE) designed for Mach 2.32 can have transonic airflow requirements as high as 1.6 times the cruise airflow. This is a formidable requirement for conventional, high performance, axisymmetric, translating centerbody mixed compression inlets. An alternate inlet is defined where the second cone of a two cone centerbody collapses to the initial cone angle to provide a large off-design airflow capability, and incorporates modest centerbody translation to minimize spillage drag. Estimates of transonic spillage drag are competitive with those of conventional translating centerbody inlets. The inlet's cruise performance exhibits very low bleed requirements with good recovery and high angle of attack capability.

256. WASSERBAUER, J. F.; NEUMANN, H. E.; SHAW, R. J.: **Distortion in a full-scale bicone inlet with internal focused compression and 45 percent internal contraction.** : NASA-TM-X-3133 E-7992 1974. 75N11970

The distortion characteristics were investigated at the subsonic diffuser exit of a full-scale, Mach 2.5, axisymmetric, mixed compression inlet. Performance and steady-state distortion characteristics were obtained at zero and maximum angle of attack and during an inlet unstart-restart sequence. For the configuration with no cowl bleed, steady-state distortion P(max)P(min)P(bar) ranged from 0.10 for critical inlet operation at 0 deg

angle-of-attack to 0.306 for supercritical inlet operation at 6.84 deg angle-of-attack. Vortex generators provided a 50 percent reduction in steady-state distortion for critical operation. Bleed has a smaller effect on steady-stated distortion.

257. WILSON, J. R.; WRIGHT, B. R.: **Airframe engine integration with variable cycle engines.** AIAA PAPER 77-798 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 13th, Orlando, Fla., July 11-13, 1977, AIAA 8 p. 1977. 77A41961

The paper studies the feasibility of using variable cycle engines, which have the ability to operate like turbofans during subsonic cruise and like turbojets at supersonic cruise, to regulate airflow and better match the engine with the inlet and reduce off-design penalties for second generation SST designs employing the over/under concept of engine installation. A study of engine performance penalties related to inlet matching was performed on a advanced SST baseline aircraft with under/over nacelles containing VCE's with two different mixed compression inlet designs: a translating centerbody axisymmetric inlet, and a two-dimensional, articulated centerbody, vertical wedge. Mission analyses show that the variable geometry features of VCE's allow engine airflow to be scheduled to match either type of inlet for minimum installations costs.

258. BROOKS, A. J.; DADD, G. J.: **Mixed compression air intakes for operation at Mach 2.2.** NGTE-R-330 BR42755 1974. 75X71310 US GOV AGENCIES AND CONTRACTORS

259. BROOKS, A. J.; DADD, G. J.: **Mixed compression air intakes for operation at Mach 2.2.** International Symposium on Air Breathing Engines, 2nd, Sheffield, England, March 24-29, 1974, Proceedings. (74A39964 20-28) London, Royal Aeronautical Society, 1974. 16 p. 1974. 74A39981

Model tests on a series of mixed compression intakes, at conditions equivalent to Mach 2.2 flight, led to the development of an intake bleed arrangement which permitted continuous operation over an adequate mass flow range and with acceptable engine flow distortion levels. An analysis method was developed for comparing intakes in terms of their effects on payload. This was used to demonstrate a payload performance improvement of 5.5% for the best model tested, relative to typical external compression intakes, with a potential for a further 2% improvement following further development.

260. HAAGENSON, W. R.; RANDALL, L. M.: **Inlet development for the B-1 strategic bomber.** AIAA PAPER 74-1064 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 10th, San Diego, Calif., Oct. 21-23, 1974, AIAA 9 p. 1974. 75A10258

The B-1 inlet was originally a mixed compression design, but later changed to an external compression inlet (ECI). All major problems encountered in adapting the ECI to the B-1 were solved during the first wind tunnel development test. Aerodynamic characteristics of the inlet and, particularly, the characteristics of certain inlet control parameters are associated with the underwing location of the nacelle. Inlet distortion and inlet/engine compatibility have been carefully audited throughout the B-1 program. A demonstration of inlet/engine compatibility before first flight was provided by wind tunnel tests of a full-scale inlet/engine model at Arnold Engineering Development Center.

261. BAUMBICK, R. J.; WALLHAGEN, R. E.; NEINER, G. H.; BATTERTON, P. G.: **Dynamic response of Mach 2.5 axisymmetric inlet with 40 percent supersonic internal area contraction.**: NASA-TM-X-2833 E-7426 1973. 73N27709

Results of experimental tests conducted on a supersonic, mixed compression, axisymmetric inlet are presented. The inlet is designed for operation at Mach 2.5 with a turbofan engine (TF-30). The inlet was terminated with either a choked-orifice plate or a long pipe with variable area choked exit plug. Frequency responses were obtained for selected static pressures in the diffuser. These pressures were selected as potential control signals for terminal shock control. Frequency responses were obtained for the Mach 2 and 2.5 conditions for different terminations. Responses also were obtained with and without cowl bleed. Internal disturbances were produced by sinusoidally varying the inlet overboard bypass doors at frequencies out to 100 hertz.

262. BOWDITCH, D. N.: **Some design considerations for supersonic cruise mixed compression inlets.**: AIAA PAPER 73-1269 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 9th, Las Vegas, Nev., Nov. 5-7, 1973, AIAA 19 p. 1973. 74A12496

A mixed compression inlet designed for supersonic cruise has very demanding requirements for high total pressure recovery and low bleed and cowl drag. However, since the optimum inlet for supersonic cruise performance may

have other undesirable characteristics, it is necessary to establish trade-offs between inlet performance and other inlet characteristics. The paper will review some of these trade-offs between the amount of internal compression, aerodynamic performance and angle-of-attack tolerance. Also some techniques in use at the Lewis Research Center for analysis of boundary layer control and subsonic diffuser flow will be discussed.

2.7 THROUGH-FLOW FAN INLETS

263. BARNHART, PAUL J.; **A supersonic through-flow fan engine airframe integration study - Final report.**: NASA-CR-185140; E-5068; NAS 1.26:185140; AIAA-89-2140. Presented at the Aircraft Design, Systems and Operations Conference, Seattle, WA, 31 July - 2 Aug. 1989; cosponsored by AIAA, AHS, and ASEE, 11 p., Sept. 1989. 90N10004.

264. BARNHART, PAUL J.: **A preliminary design study of supersonic through-flow fan inlets.** AIAA PAPER 88-3075 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 11 p. 88A53137

From Mach 3.20 cruise propulsion systems, preliminary design studies for two supersonic through-flow fan primary inlets and a single core inlet were undertaken. Method of characteristics and one-dimensional performance techniques were applied to assess the potential improvements supersonic through-flow fan technology has over more conventional systems. A fixed geometry supersonic through-flow fan primary inlet was found to have better performance than a conventional inlet design on the basis of total pressure recovery, air flow, aerodynamic drag and size and weight.

265. BARNHART, PAUL J.: **A preliminary design study of supersonic through-flow fan inlets.** NASA-CR-182224 E-4490 NAS 1.26:182224
1988. 89N11751

From Mach 3.20 cruise propulsion systems, preliminary design studies for two supersonic through-flow fan primary inlets and a single core inlet were undertaken. Method of characteristics and one dimensional performance techniques were applied to assess the potential improvements supersonic through-flow fan technology has over more conventional systems. A fixed geometry supersonic through-flow fan primary inlet was found to have better performance than a conventional inlet design on the basis of total pressure recovery, air flow, aerodynamic drag and size and weight.

2.8 OTHER INLETS

266. FINK, L. E.; DUNN, B. M.; MARRS, K. J.; CLAUSEN, ROBERT: **Experimental investigation of a 2D supersonic inlet with a pivoting cover (U).** 1987. 90X71391 **DOMESTIC**

267. DUNN, B. M.: **Performance and operating characteristics of a 2D supersonic inlet with a pivoting cover (U).** 1986. 88X72072 **DOMESTIC**

268. DEFATTA, M. R.: **Model test of an advanced F-16 variable-ramp inlet at Mach 2.2 to 2.5.** NASA-CR-3879 E-2431 NAS 1.26:3879 ERR-FW-2166 1985. 85X10179 **DOMESTIC**

A 0.15-scale model of a Mach 2.2 design variable ramp inlet for advanced versions of the F-16 Multirole Fighter was tested from Mach 2.2 to 2.5 at a wide range of angles of attack and sideslip. The current maximum second ramp angle for this inlet is 20.8 deg. Data were obtained at second ramp angles of 20 deg, 22 deg, and 24 deg to investigate and document inlet operation at both the current maximum ramp angle and at the higher angles possible in future designs or modifications. The inlet was tested with the standard F-16 forebody and a large radome under consideration for growth versions of the F-16. With the current maximum ramp angle of 20.8 deg and the standard F-16A nose, pressure recovery was inadequate to achieve required airplane performance at Mach 2.5, although inlet stability and distortion were good. When tested with maximum ramp angles up to 24 deg, this configuration performed adequately at all Mach numbers tested. With the proposed large radome, pressure recovery is adequate at Mach 2.5, but increased second-ramp angles (22 deg or higher) will be required to insure adequate stability at the higher Mach numbers.

269. GAJEWSKI, T.: **Nostrils of supersonic aircraft.** AD-B089946L FTD-ID(RS)T-1139-84 1984. 85X74255 **US GOV AGENCIES**

270. EVELYN, G. B.; TJONNELAND, E.; GRANDE, D. L.: **Studies of advanced supersonic technologies.** NASA-CR-166076 NAS 1.26:166076 D6-51156. 1983. 83X10331 US GOV AGENCIES AND CONTRACTORS

Several propulsion and structural technology advancements that offered high potential for application to future supersonic transports were investigated. Propulsion: Inlet Flow Analysis: A 3-D boundary layer program and a 3-D shock/boundary layer interaction program were completed and combined with a method of characteristics program to yield a flow analysis procedure for a supersonic diffuser of an axisymmetric inlet at angle of attack. The analysis was applied to the P-inlet operating at angle of attack to illustrate the procedure. Inlet Controls: Modern technology was applied to the controls of a mixed compression inlet to develop an integrated airframe, inlet, engine simulation, and baseline inlet and engine controllers. The inlet control was implemented in a flight type, fault tolerant, triple channel controller. Nacelle Integration Analysis: Coupling of a nonlinearized potential flow solution embedded in a general solution of a larger domain using linearized potential flow was accomplished through a four step process and was applied through a preliminary analysis of a nacelle wing combination. NACA Nozzle Test: Analysis, design and laboratory testing was accomplished to verify predicted performance and secondary flow pumping capabilities of the Naturally Aspirated Co-annular (NACA) nozzle concept. Installed Nozzle Test Program: Test techniques and procedures for evaluating various nozzle concepts and installations were investigated as to their effect on airplane performance at transonic speeds and as a means of establishing configuration preliminary drag values.

271. NELSON, D. P.: **Model aerodynamic test results for a refined actuated inlet ejector nozzle at simulated takeoff and cruise conditions comprehensive data report. Volume 1: Design drawings.** NASA-CR-168052-Vol-1 NAS 1.26:168052-Vol-1 PWA-5768-30-VOL-1 1983. 83X10239 US GOV AGENCIES AND CONTRACTORS

Wind tunnel model tests were conducted to demonstrate the aerodynamic performance improvements of a refined actuated inlet ejector nozzle. Models of approximately one-tenth scale were configurated to simulate nozzle operation at takeoff, subsonic cruise, transonic cruise and supersonic cruise. Variations of model components provided a performance evaluation of ejector inlet and exit area, forebody boattail angle and ejector inlet operation in the open and closed mode. Approximately 700 data points were acquired at Mach numbers of 0, 0.36, 0.9, 1.2, and 2.0 for a wide range of nozzle flow conditions. Results show that relative to two ejector nozzles previously tested performance was improved significantly at takeoff and subsonic cruise. Takeoff quiescent and fly-over performance was improved 0.3 and 1.6 percent respectively. At subsonic cruise a 4.2 percent improvement was demonstrated. Good supersonic cruise performance, a C(f) of 0.982, was attained equal to the high performance of the previous tests. The established advanced supersonic transport propulsion study performance goals were met or closely approached at takeoff and supersonic cruise. Subsonic cruise performance was within 2.3 percent of the target. Design drawings of the nozzle model are presented.

272. BOWDITCH, D. N.: **Supersonic conformal inlet design**. In NASA Langley Research Center Tactical Aircraft Res. and Technol., Vol. 1, Pt. 2, p 585-596 (See 81X10184 03-01) 1981. 81X10195 US GOV AGENCIES AND CONTRACTORS

A conformal inlet, designed for an advanced F-16 aircraft, is described that combines the low drag and structural efficiency characteristics of an axisymmetric inlet with the simple variable geometry and high angle of attack tolerance of a rectangular inlet. The inlet was designed by an approximate use of two dimensional supersonic flow analysis. Emerging computational fluid mechanics codes are described and demonstrated. They permit the design of more innovative conformal inlets that should significantly improve propulsion airframe integration for aircraft that cruise supersonically.

273. JOHNSON, P.; EVELYN, G.: **Supersonic inlet technology**. In its Advan. Concept Studies for Supersonic Vehicles, 16 p (See 82X10002 01-01) 1981. 82X10009 US GOV AGENCIES AND CONTRACTORS

The results of the NASA P-inlet high-speed test program, which produced analytical input and validation data for both the flow code development and the control system concept studies are reported. The status of the three dimensional flow code development and initial validation studies is provided. The work conducted on the inlet control system and its simulation is described. The test planning and parts fabrication for the P-inlet low-speed performance and noise attenuation testing are covered.

2.9 EXPERIMENTAL INVESTIGATIONS

274. SAJBEN, MIKLOS; DONOVAN, JOHN F.; MORRIS, MARTIN J.: **Experimental investigation of terminal shock sensors in mixed-compression inlets.** AIAA PAPER 90-1931 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 26th, Orlando, FL, July 16-18, 1990. 11 p. 90A40560

This paper describes experimental investigations of devices designed for the nonintrusive detection of terminal shock location in mixed-compression inlets at high supersonic flight speeds. Systems based on sensing wall pressures by an array of wall-mounted transducers were selected for detailed study. Pressure signals were processed by three different methods: (1) interpretation of instantaneous pressure distributions, (2) detection of the turbulent intensity amplification occurring at the shock,and (3) determination of the upstream limit to which a search-tone, introduced at the downstream end of the channel, can propagate. The first two of these methods were tested in real time. The third method appeared feasible for weak shocks only; at high shock strengths, propagation upstream of the source could not be detected.

275. HAYNES, DAVY A.; MILLER, DAVID S.; KLEIN, JOHN R.; LOUIE,CHECK M.: **Design and experimental verification of an equivalent forebody representation of flowing inlets.** (AIAA, Aerospace Sciences Meeting, 26th, Reno, NV, Jan. 11-14, 1988, AIAA Paper 88-0195) Journal of Aircraft (ISSN 0021-8669), vol. 26, Dec. 1989, p. 1059-1066. Previously cited in issue 07, p. 929, Accession no. 88A22143. 1989. 90A17863

276. LEYNAERT, JACKY: **Wind tunnel air intake test techniques.** 1988. 89N16751

The general concept and validation of wind tunnel intake test setups are reviewed. The main intake test parameters are defined. Test rigs adapted to subsonic transport intakes, and to supersonic or combat aircraft intakes at supersonic Mach number, at transonic, and low speed are discussed. Devices for unsteady flow analysis, and for detailed inner flow probing are mentioned.

277. LEYNAERT, JACKY: **Wind tunnel air intake test techniques.**: ONERA, TP NO. 1988-20 (Institut von Karman de Dynamique des Fluides, Lecture Series, Brussels, Belgium, Feb. 22-26, 1988) ONERA, TP, no. 1988-20, 1988, 30 p. 1988. 89A29210

The development of aircraft propulsion system air intake testing methods over the last decade is presently noted to have progressed in the direction of large-scale intake testing, with detailed digitized analysis of the steady and unsteady flow in order to guide CFD efforts for the given installation. Attention is presently given to intake test parameters and the effects on various kinds of interference on them, the state-of-the-art in subsonic transport aircraft intake mass-flow and cowl drag testing, combat aircraft and SST air intake internal flow tests and nacelle external drag, and special test methods for total internal flow probing.

278. IAO, LIANG: **A flight-test study on the total pressure recovery and exit flow field in an inlet.** Journal of Aerospace Power, vol. 1, Oct. 1986, p. 154-156, 188, 189. In Chinese, with abstract in English. 1986. 87A27487

A flight-test study on the total pressure recovery and the exit flow field in an inlet of a supersonic jet aircraft is presented. The total pressure recovery characteristics and the exit total pressure distortion patterns in the transonic flight are given. The variation of the total pressure recovery coefficient and the distortion factor with Mach number during inlet-engine matching is illustrated. The flight test study provides valuable data for research on inlet-engine compatibility.

279. KAPOOR, K.; PAI, T. G.: **Experimental studies on subcritical intakes flows.**: International Council of the Aeronautical Sciences, Congress, 14th, Toulouse, France, September 9-14, 1984, Proceedings. Volume 2 (84A44926 22-01). New York, American Institute of Aeronautics and Astronautics, 1984, p. 1024-1029. Research supported by the Ministry of Defence of India. 1984. 84A45040

An experimental study on two-dimensional external compression supersonic air intakes, leading to development of subcritical flow models, forms the objective of present paper. Intake models incorporating variable geometry feature and a mass flow measuring and monitoring unit have been tested for Mach number range of 1.6 to 2.2. Based on the experimental data, a subcritical flow model correlating intake geometry, shock stand-off distance and free stream Mach number has been developed. Additive drag and stable range of intake operation using flow model evolved has been compared with the corresponding values reported in the literature

and those which were obtained during current experiments. Two types of flow instabilities have also been observed.

280. YETTER, J. A.; SALEMANN, V.; SUSSMAN, M. B.: **Inlet flow field investigation. Part 1: Transonic flow field survey**.: NASA-CR-172239 NAS 1.26:172239 D180-27738-1 1984. 84N15123

A wind tunnel investigation was conducted to determine the local inlet flow field characteristics of an advanced tactical supersonic cruise airplane. A data base for the development and validation of analytical codes directed at the analysis of inlet flow fields for advanced supersonic airplanes was established. Testing was conducted at the NASA-Langley 16-foot Transonic Tunnel at freestream Mach numbers of 0.6 to1.20 and angles of attack from 0.0 to 10.0 degrees. Inlet flow field surveys were made at locations representative of wing (upper and lower surface) and forebody mounted inlet concepts. Results are presented in the form of local inlet flow field angle of attack, sideflow angle, and Mach number contours. Wing surface pressure distributions supplement the flow field data.

281. SYBERG, J.; TURNER, L.: **Supersonic test of a mixed-compression axisymmetric inlet at angles of incidence**. NASA-CR-165686 1981. 81X10213 US GOV AGENCIES AND CONTRACTORS

Data obtained during wind tunnel testing of a large scale, axisymmetric, supersonic inlet and an analysis of the inlet performance during operation at angle of incidence are presented. Duct dynamic pressures were recorded to support the development of advanced inlet control systems. The inlet bleed system was adjusted to provide acceptable inlet performance over a wide range of Mach numbers and angles of incidence. Windward and leeward side pressure profiles were obtained by recording data at both positive and negative model angles of attack at identical test conditions. Static pressure profiles in the transverse plane were obtained by rolling the model 90 deg in the wind tunnel and repeating the test conditions. Inlet control signal data were recorded for a wide range of inlet operating conditions and data for dynamic model validation at angle of attack were obtained.

282. HAAS, M.; KARANIAN, A. J.: **Small-scale supersonic inlet test facility**. AIAA PAPER 80-1145. AIAA, SAE, and ASME, Joint Propulsion Conference, 16th, Hartford, Conn., June 30-July 2, 1980, AIAA 10 p. 1980. 80A38937

A series of small-scale isolated inlet model tests conducted in a newly developed low cost small-scale supersonic inlet testing facility at United Technologies Research Center demonstrates the efficacy of such tests as a means of determining full-scale supersonic inlet performance. The central component of the facility is a supersonic wind tunnel having a 4-in. x 4-in. test section. The test data demonstrate that the tunnel can accommodate both axisymmetric and two-dimensional isolated inlets of a size permitting installation of sufficient instrumentation to obtain all necessary inlet performance data. Tests with these inlets have been made over a Mach number range of 2 to 4 and angles of attack from -4 to 9 deg. The wind tunnel is operated in either the continuous, semicontinuous or blowdown mode, depending on the desired test condition. Inlet Reynolds numbers (based on inlet diameter) of approximately one million are attainable during the continuous mode of operation. The inlet performance data obtained was in good agreement with data obtained on the same or similar inlet models tested in larger facilities.

283. GRANDJACQUES, M.: **Unsteady flow measurements in air intakes**.: AAAF-NT-79-16 ISBN-2-7170-0543-9 1979. 80N18005

The means for studying the steady and unsteady flow of air intakes by measuring the pressures at the compressor inlet plane are described. Improved instantaneous differential pressure measurement devices are described which extend the range of utilization from 40 C to 100 C and compensate the zero and sensitivity thermal offsets. The system was assembled for simultaneous measurement in 40 channels at a rate of up to 1700 pressure measurements per second. The results show that the system is adequate for industrial applications, yielding a precision range on the order of 0.5%.

2.10 COMPUTATIONAL FLUID DYNAMICS

284. VARNER, M. O.: **LAPIN - Large perturbation flow field analysis and simulation for supersonic inlets**. LEW-14324 90M10670

The LAPIN computer program was developed to analyze the large perturbation, transient flow fields in supersonic mixed-compression inlets. The analytical study of large-scale transient flow phenomena in supersonic inlets and their interaction with the engine flow is of primary importance to inlet design and control. The optimum design of the inlet, its associated auxiliary air systems,

and the inlet control system are based on an understanding of the effects of these transients on the inlet flow history and their attendant effect on inlet control and performance. LAPIN can be used as a versatile analysis tool for simulating supersonic inlet unstart, restart and hammershock with emphasis on evaluation of control system requirements, and prediction of transient duct overpressure. LAPIN is based on a quasi-one-dimensional, inviscid, unsteady approach which includes engineering models of unstart/restart, bleed, bypass, and geometry effects. Numerical solution of the governing time-dependent equations of motion is accomplished through a shock-capturing finite difference algorithm. Implicit solution algorithms provide fast solutions under slow transients or time-asymptotic conditions. Explicit solution algorithms yield efficient solutions for highly transient flows. Implementation of split-flux schemes provide robust solutions for highly transient flows with moving shocks. To accurately model inlet flows, LAPIN utilizes precise inlet and exit plane boundary conditions. For the exit plane, these include specified exit plane pressures and corrected mass flow as a function of time. For the inflow boundary, these include the specified Mach number for the fully started inlet and code adaptable to model inlet unstart. LAPIN utilizes both explicit and totally implicit boundary conditions in the inlet code to provide totally compatible numeric schemes. LAPIN includes a number of sophisticated engineering features for treating real inlets such as translating center bodies, throat bleed, moving ramps, and variable engine bypass flow - all with real-time variation. LAPIN is written in FORTRAN IV (IBM Level G) for batch execution and has been implemented on an IBM 370 series computer operating under OS with a central memory requirement of approximately 400K of 8 bit bytes. Both single precision and double precision versions of the program are included on the distribution tape. LAPIN was developed in 1984.

285. SORENSON, R. L.: **Flow fields in supersonic inlets.** ARC-11098. 1990. 90M10016

This computer program is designed to calculate the flow fields in two-dimensional and three-dimensional axisymmetric supersonic inlets. The method of characteristics is used to compute arrays of points in the flow field. At each point the total pressure, local Mach number, local flow angle, and static pressure are calculated. This program can be used to design and analyze supersonic inlets by determining the surface compression rates and throat flow properties. The program employs the method of characteristics for a perfect gas. The basic equation used in the program is the compatibility equation which relates the change in stream angle to the change in entropy and the change in velocity. In order to facilitate the computation, the flow field behind the bow shock wave is broken into regions bounded by shock waves. In each region successive rays are computed from a surface to a shock wave until the shock wave intersects a surface or falls outside the cowl lip. As soon as the intersection occurs a new region is started and the previous region continued only in the area in which it is needed, thus eliminating unnecessary calculations. The maximum number of regions possible in the program is ten, which allows for the simultaneous calculations of up to nine shock waves. Input to this program consists of surface contours, free-stream Mach number, and various calculation control parameters. Output consists of printed and/or plotted results. For plotted results an SC-4020 or similar plotting device is required. This program is written in FORTRAN IV to be executed in the batch mode and has been implemented on a CDC 7600 with a central memory requirement of approximately 27k (octal) of 60 bit words.

286. ANDERSON, B. H.: **Design of supersonic inlets.** LEW-10868 90M10536

This FORTRAN IV computer program which incorporates the method of characteristics was written to assist in the design of supersonic inlets. There were two objectives: (1) to study a greater variety of supersonic inlet configurations and (2) to reduce the time required for trial-and-error procedures to arrive at optimum inlet design. The computer program was written with the intention of being able to construct a variety of inlet configurations by interchanging specific subroutines. In this manner, greater flexibility of choice was attained, and the time required to program a specific inlet configuration was greatly reduced. The second objective was accomplished by a reformulation of the boundary value problem for hyperbolic equations. By this reformulation of the boundary data, the engineering design quantities, throat Mach number and flow angle, were introduced as direct input quantities to the computer program. As a consequence of introducing the engineering parameters as input, the computer program will calculate the surface contours required to satisfy the specific throat conditions. Inviscid flow is assumed and the method used to calculate the inlet contour results in minimum distortion to the flow in the throat. This program was developed on an IBM7094.

287. SHIGEMATSU, JUNJI; YAMAMOTO, KAZUOMI; SHIRAISHI, KAZUO; TANAKA, ATSUSHIGE: **A numerical investigation of supersonic inlet using implicit TVD scheme.** AIAA PAPER 90-2135 AIAA, SAE, ASME, and ASEE, Joint

Propulsion Conference, 26th, Orlando, FL, July 16-18, 1990. 10 p. 1990. 90A40612

The compressible Navier-Stokes equations were solved to investigate supersonic inlet flow field. In two-dimensional analysis, the mass flow plug which control the back pressure was modeled numerically for close modeling of experimental case. The three-dimensional computation was done to predict three-dimensional flow behavior such as corner vortex and interaction between oblique shock wave and side wall turbulent boundary layer. The two-dimensional numerical analysis could predict the complicated flow field on various mass flow plug condition respectively. The results by three-dimensional computation could show the viscous effects caused by the interaction between ramp oblique shock wave and the side wall turbulent boundary layer. The computations were compared with the experimental results of wind tunnel test. The numerical solutions were successfully agreed with the experimental results.

288. KENNON, STEPHEN R.: **Supersonic inlet calculations using an upwind finite-volume method on adaptive unstructured grids**. AIAA PAPER 89-0113 AIAA, Aerospace Sciences Meeting, 27th, Reno, NV, Jan. 9-12, 1989. 8 p. 1989. 89A25100

Euler calculations are presented using an upwind finite-volume method on adaptive unstructured grids. The method combines the attractive features of upwind methods with the geometric generality provided by the use of unstructured grids. The flow solver is coupled to an adaptive unstructured grid generation method developed for non-convex domains. Results are presented for representative transonic and supersonic flows including high-speed, complex-geometry inlet flows.

289. CHYU, W. J.; KAWAMURA, T.; BENCZE, D. P.: **Calculation of external-internal flow fields for mixed-compression inlets**. (University of Texas, NSF, U.S. Navy, et al., World Congress on Computational Mechanics, 1st, Austin, TX, Sept. 22-26, 1986) Computer Methods in Applied Mechanics and Engineering (ISSN 0045-7825), vol. 64, Oct. 1987, p. 21-37. Previously announced in STAR as 87N24434. 88A37353

Supersonic inlet flows with mixed external-internal compressions were computed using a combined implicit-explicit (Beam-Warming-Steger/MacCormack) method for solving the three-dimensional unsteady, compressible Navier-Stokes equations in conservation form. Numerical calculations were made of various flows related to such inlet operations as the shock-wave intersections, subsonic spillage around the cowl lip, and inlet started versus unstarted conditions. Some of the computed results were compared with wind tunnel data.

290. KIM, Y.-N.; BUGGELN, R. C.; MCDONALD, H.: **Numerical analysis of some supersonic viscous flows related to inlet and nozzle systems.** AIAA PAPER 86-1597 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd, Huntsville, AL, June 16-18, 1986. 13 p. 86A42738

A numerical method originally developed for three-dimensional supersonic inlet flow calculations is extended and applied to the study of two-dimensional and three-dimensional flows associated with arbitrary propulsion systems. The method is based on the forward spatial marching solution of a reduced form of the three-dimensional steady Navier-Stokes equations in which streamwise pressure gradients are retained in both the subsonic and supersonic regions. The present paper briefly describes the analysis and then shows three applications. In the first application, a wall transpiration study has been performed for the two-dimensional shock wave/turbulent boundary layer interaction flow field with application to an inlet configuration. The second application treats a rectangular high speed inlet with a swept sideplate including the effects of sideplate spillage. Finally, the method is utilized to analyze the interaction of an under-expanded supersonic jet with an ambient flow. Computed results are examined and compared with available experimental measurements. It is demonstrated that the present numerical method is capable of numerically simulating complex two- and three-dimensional flows relevant to hypersonic propulsion systems in a manner which both shows good agreement with data when such data is available, and which shows the complex flow features in the absence of data.

291. YAGHMAEE, S.; ROBERTS, D. W.: **A numerical algorithm for simulating 3D viscous supersonic inlet flows.** AIAA PAPER 86-0552 AIAA, Aerospace Sciences Meeting, 24th, Reno, NV, Jan. 6-9, 1986. 12 p. Navy-supported research. 86A22705

A new numerical method has been incorporated into a prototype code for modeling three-dimensional inlet flow fields. The method is based on the coupling of a parabolized Navier-Stokes (PNS) analysis with an elliptic relation for the three-dimensional pressure field (EP). The resulting PNS/EP analysis provides converged steady state solutions of the fully elliptic Navier-Stokes equations with streamwise diffusion neglected. The feasibility of this approach was initially proven using a quasi-one-

dimensional analysis. A convergent-divergent channel flow field with a normal shock was accurately computed. The computational efficiency of the PNS/EP algorithm was demonstrated to be superior to advanced time-dependent methods. The prototype three-dimensional PNS/EP code was successfully used to capture a normal shock in a three-dimensional internal divergent channel flow field.

292. HUNTER, L. G.; TRIPP, J. M.; HOWLETT, D. G.: **Supersonic inlet study using the Navier-Stokes equations.** (AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 21st, Monterey, CA, July 8-10, 1985, AIAA Paper 85-1211) Journal of Propulsion and Power (ISSN 0748-4658), vol. 2, Mar.-Apr. 1986, p. 181-187. Previously cited in issue 19, p. 2742, Accession no. 85A40820. 1986. 86A31598

293. WOAN, C. J.: **A user-oriented numerical procedure for generating orthogonal inlet grids and its application to Euler-flow calculations.** AIAA PAPER 86-0496. AIAA, Aerospace Sciences Meeting, 24th, Reno, NV, Jan. 6-9, 1986. 11 p. Research supported by the Rockwell International Independent Research and Development Program. 1986. 86A19907

A user-oriented numerical procedure is presented for generating orthogonal grids for inlets with or without centerbody. The procedure uses a hybrid conformal mapping/Laplace'sequation/conjugate-harmonic-function-construction technique coupled with computer graphics to interactively generate grids. A multigrid method is used to accelerate convergence of Laplace grid generator. Boundary grid spacing is controlled by a segmented method in the transformed plane using a simple distribution function. The procedure greatly reduces user's burden in distributing boundary points and has been applied to several inlet configurations for Euler-flow calculations at subsonic, transonic, and supersonic speeds.

294. CHYU, W. J.; KAWAMURA, T.; BENCZE, D. P.: **Calculation of external-internal flow fields for mixed-compression inlets.** NASA-TM-88362 A-86409 NAS 1.15:88362 1986. 87N24434

Supersonic inlet flows with mixed external-internal compressions were computed using a combined implicit-explicit (Beam-Warming-Steger/MacCormack) method for solving the three-dimensional unsteady, compressible Navier-Stokes equations in conservation form. Numerical calculations were made of various flows related to such inlet operations as the shock-wave intersections, subsonic spillage around the cowl lip, and inlet started versus unstarted conditions. Some of the computed results were compared with wind tunnel data.

295. POVINELLI, LOUIS A.; TOWNE, CHARLES E.: **Viscous analyses for flow through subsonic and supersonic intakes.** NASA-TM-88831 E-3209 NAS 1.15:88831 1986. 87N15173

A parabolized Navier-Stokes code was used to analyze a number of diffusers typical of a modern inlet design. The effect of curvature of the diffuser centerline and transitioning cross sections was evaluated to determine the primary cause of the flow distortion in the duct. Results are presented for S-shaped intakes with circular and transitioning cross sections. Special emphasis is placed on verification of the analysis to accurately predict distorted flow fields resulting from pressure-driven secondary flows. The effect of vortex generators on reducing the distortion of intakes is presented. Comparisons of the experimental and analytical total pressure contours at the exit of the intake exhibit good agreement. In the case of supersonic inlets, computations of the inlet flow field reveal that large secondary flow regions may be generated just inside of the intake. These strong flows may lead to separated flow regions and cause pronounced distortions upstream of the compressor.

296. HESS, J. L.; FRIEDMAN, D. M.; CLARK, R. W.: **Calculation of compressible flow about three-dimensional inlets with auxiliary inlets, slats and vanes by means of a panel method.** AIAA PAPER 85-1196. AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 21st, Monterey, CA, July 8-10, 1985. 9 p. 1985. 85A40817

An efficient and user-oriented method has been constructed for calculating flow in and about complex inlet configurations. Efficiency is attained by: the use of a panel method, a technique of superposition for obtaining solutions at any inlet operating condition, and employment of an advanced matrix-iteration technique for solving large full systems of equations, including the nonlinear equations for the Kutta condition. User concerns are addressed by the provision of several novel graphical output options that, taken together, yield a more complete comprehension of the flow field than had been possible previously. Examples of these features are presented for some complicated configurations, and where possible, comparisons are made between calculation and experiment.

297. KERLICK, G. D.: **Adaptive mesh solution for supersonic conical flow in a rectilinear inlet**. AIAA PAPER 85-1626. American Institute of Aeronautics and Astronautics, Fluid Dynamics and Plasmadynamics and Lasers Conference, 18th, Cincinnati, OH, July 16-18, 1985. 12 p. 1985. 85A40732

Solutions for the inviscid and viscous supersonic conical flow in a complete rectilinear inlet consisting of four planes intersecting at arbitrary wedge and sweep angles are obtained. To compute the flow on a specially constructed mesh, a three-dimensional flow solver ARC3D is used. It is shown that a single-pass mesh re-adaptation procedure can be used to obtain improved shock capture without the necessity of modifying the flow code, provided that the flow solver works in curvilinear coordinates and is restartable. Results computed by the method show good agreement with experimental measurements and previous calculations.

298. INOUE, K.: **Grid generation for inlet configurations using conformal mapping**. Journal of Computational Physics (ISSN 0021-9991), vol. 58, March 1985, p. 146-154. 85A32633

An orthogonal grid generation method for inlet geometries is developed using conformal mapping. In this method, the region on the physical plane is mapped onto the computational plane by one or two steps of conformal mapping; the mapping functions are determined numerically. A simple extension of this method allows the generation of three-dimensional grids for asymmetric geometries. Grids of H-type are also generated through the fundamental mapping function for C-type grids.

299. HUNTER, L. G.; TRIPP, J. M.; HOWLETT, D. G.: **A Mach 2.0 plus supersonic inlet study using the Navier-Stokes equations**. AIAA PAPER 85-1211. AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 21st, Monterey, CA, July 8-10, 1985. 12 p. 85A40820

The 3-D, unsteady, compressible Navier-Stokes equations were numerically solved for the flow field about three external-compression inlet configurations. Configuration 1 was a generic Mach 2.2 variable-geometry two-ramp inlet with a bleed slot. Configuration 2 was an F-16/79 inlet at Mach 2.0 with porous-ramp bleed and slot bleed. For these configurations, two different approaches were used to model the bleed. Configurations 1 and 2 were modeled by using three lateral planes in the 3-D code with symmetry around the center plane, which provides an equivalent 2-D solution. Configuration 3 was an axisymmetric spike inlet at Mach 2.2 at zero degrees angle of attack. A full 3-D solution was obtained for this configuration. For configurations 2 and 3, the computed surface pressures are in good agreement with the experimental data for cases with and without bleed.

300. BUSH, R. H.: **External compression inlet predictions using an implicit, upwind, multiple zone approach**. AIAA PAPER 85-1521: Computational Fluid Dynamics Conference, 7th, Cincinnati, OH, July 15-17, 1985, Technical Papers (85A40926 19-34). New York, AIAA, 1985, p. 438-447. 85A40966

The present zonal methodology for existing time-dependent numerical codes is based on boundary conditions that are currently popular in treatments of inflow and outflow boundaries, and, since it may be characterized as a modification of the boundary conditions with a scheme for communicating between zones, it is easily incorporated into numerical codes. The methodology can be extended to three dimensions, and provides a straight forward means for the computation of complex geometric configurations by subdividing the computational domain into a series of simple zones. The methodology is used to compute the performance of an external compression inlet, for which it yielded detailed data on such inherently two-dimensional phenomena as boundary layer behavior and cowl lip flows.

301. ALEKSANDROVICH, E. V.; ZABELIN, IU. A.: **Wave drag of a supersonic air intake at high subsonic velocities**. TsAGI, Uchenye Zapiski(ISSN 0321-3429), vol. 16, no. 5, 1985, p. 102-107. In Russian. 86A48834

An inviscid unseparated flow model is used to calculate the wave drag coefficient of a supersonic air intake operating in the throttling mode inflow at a freestream Mach number of 0.85. Calculation results are compared with experimental data. It is concluded that, at high subsonic flight velocities, the separation drag constitutes only an insignificant part of the drag connected with the formation of shocks on the outer surface of the casing.

302. OBIKANE, Y.: **Numerical computation of the Reynolds stress in supersonic inlet flows**. AIAA PAPER 84-1364. AIAA, SAE, and ASME, Joint Propulsion Conference, 20th, Cincinnati, OH, June 11-13, 1984.9 p. 84A35193

The prediction of the Reynolds stress in an axisymmetric supersonic inlet
flow is demonstrated. To predict the Reynolds stress a computational method and a second order turbulence

model have been proposed. For the bench mark test of the turbulence model, a supersonic compression corner flow is computed. The bench mark results agree qualitatively with the experiment. The simple method is quite practical and useful for designers who treat properties related to turbulent kinetic energy, such as the flows in ramjet engines or the prediction of noise generated from the tips of the fan.

303. FAIDY, J. P.: **A finite difference model for flows around an air intake.** AAAF PAPER NT 84-11 Association Aeronautique et Astronautique de France, Colloque d'Aerodynamique Appliquee, 21st, Ecully,France, Nov. 7-9, 1984. 45 p. In French. 1984. 85A48991

A finite difference model is presented for simplifying the calculations necessary for designing air intake ducts for high performance military aircraft. The potential equation for a perfect fluid is written in nonconservative form in cylindrical coordinates. Account is taken of the presence of a conical object in the duct to assure flow stability in the presence of supersonic shocks. The three-dimensional geometry of the intake and cone is treated in terms of a series of longitudinal cross-sections in rotation from the center of the cone. Sample calculations for supersonic flow phenomena in the intake, when compared with wind tunnel data, show satisfactory agreement even though entropy and viscous effects are neglected.

304. HOFFMAN, J. D.; BISHOP, A. R.; VADYAK, J.: **Three-dimensional flow simulations for supersonic mixed-compression inletsat incidence.** (American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 20th, Orlando, FL, Jan. 11-14, 1982, AIAA Paper 82-0061) AIAA Journal (ISSN 0001-1452), vol. 22, July 1984, p. 873-881. 84A38828

Previously in issue 07, p. 965, Accession no. 82A19778.

305. ANDERSON, B. H.: **Three-dimensional viscous design methodology for advanced technology aircraft supersonic inlet systems.**: AIAA PAPER 84-0194 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 63 p. 84A21290

A broad program to develop advanced, reliable, and user oriented three-dimensional viscous design techniques for supersonic inlet systems, and encourage their transfer into the general user community is discussed. Features of the program include: (1) develop effective methods of computing three-dimensional flows within a zonal modeling methodology; (2) ensure reasonable agreement between said analysis and selective sets of benchmark validation data; (3) develop user orientation into said analysis; and (4) explore and develop advanced numerical methodology. Previously announced in STAR as 84N13190

306. VARNER, M. O.; MARTINDALE, W. R.; PHARES, W. J.; KNEILE, K. R.; ADAMS, J. C., JR.: **Large perturbation flow field analysis and simulation for supersonic inlets.** NASA-CR-174676 NAS 1.26:174676 1984. 87N10835

An analysis technique for simulation of supersonic mixed compression inlets with large flow field perturbations is presented. The approach is based upon a quasi-one-dimensional inviscid unsteady formulation which includes engineering models of unstart/restart, bleed, bypass, and geometry effects. Numerical solution of the governing time dependent equations of motion is accomplished through a shock capturing finite difference algorithm, of which five separate approaches are evaluated. Comparison with experimental supersonic wind tunnel data is presented to verify the present approach for a wide range of transient inlet flow conditions.

307. LIU, N.-S.; SHAMROTH, S. J.; MCDONALD, H.: **Numerical solution of the Navier-Stokes equations for compressible turbulent two/three dimensional flows in the terminal shock region of an inlet/diffuser.** AIAA PAPER 83-1892: Computational Fluid Dynamics Conference, 6th, Danvers, MA, July 13-15, 1983, Collection of Technical Papers (83A39351 18-02). New York, American Institute of Aeronautics and Astronautics, 1983, p. 61-71. 1983. 83A39358

The multidimensional, ensemble-averaged, compressible, time-dependent Navier-Stokes equations in conjunction with mixing length turbulence model and shock capturing technique have been used to study the terminal shock type of flows in various flight regimes occurring in a diffuser/inlet model. The numerical scheme for solving the governing equations is based on a linearized block implicit approach and the following high Reynolds number calculations have been carried out: (1) 2-D, steady, subsonic; (2) 2-D, steady, transonic with normal shock, (3) 2-D, steady, supersonic with terminal shock, (4) 2-D, transient process of shock development and (5) 3-D, steady, transonic with normal shock. The numerical results obtained for the 2-D and 3-D transonic shocked flows have been compared with corresponding experimental data; the calculated wall static pressure

distributions agree well with the measured data. The predicted transient responses of the flow to externally applied impulsive disturbance are consistent with results obtained via asymptotic analysis.

308. LIU, N. S.; SHAMROTH, S. J.; MCDONALD, H.: **Numerical solutions of Navier-Stokes equations for compressible turbulent two/three dimensional flows in terminal shock region of an inlet/diffuser**. NASA-CR-3723 NAS 1.26:3723 1983. 83N34230

The multidimensional ensemble averaged compressible time dependent Navier Stokes equations in conjunction with mixing length turbulence model and shock capturing technique were used to study the terminal shock type of flows in various flight regimes occurring in a diffuser/inlet model. The numerical scheme for solving the governing equations is based on a linearized block implicit approach and the following high Reynolds number calculations were carried out: (1) 2 D, steady, subsonic; (2) 2 D, steady,transonic with normal shock; (3) 2 D, steady, supersonic with terminal shock; (4) 2 D, transient process of shock development and (5) 3 D, steady, transonic with normal shock. The numerical results obtained for the 2 D and 3 D transonic shocked flows were compared with corresponding experimental data; the calculated wall static pressure distributions agree well with the measured data.

309. ANDERSON, B. H.: **Three-dimensional viscous design methodology for advanced technology aircraft supersonic inlet systems**. NASA-TM-83558 E-1936 NAS 1.15:83558 AIAA-84-0192 1983. 84N13190

A broad program to develop advanced, reliable, and user oriented three-dimensional viscous design techniques for supersonic inlet systems, and encourage their transfer into the general user community is discussed. Features of the program include: (1) develop effective methods of computing three-dimensional flows within a zonal modeling methodology; (2) ensure reasonable agreement between said analysis and selective sets of benchmark validation data; (3) develop user orientation into said analysis; and (4) explore and develop advanced numerical methodology.

310. VADYAK, J.; HOFFMAN, J. D.: **Calculation of the flow field including boundary layer effects for supersonic mixed compression inlets at angles of attack**. NASA-CR-167941 NAS 1.26:167941 1982. 82N29269

The flow field in supersonic mixed compression aircraft inlets at angle of attack is calculated. A zonal modeling technique is employed to obtain the solution which divides the flow field into different computational regions. The computational regions consist of a supersonic core flow, boundary layer flows adjacent to both the forebody/centerbody and cowl contours, and flow in the shock wave boundary layer interaction regions. The zonal modeling analysis is described and some computational results are presented. The governing equations for the supersonic core flow form a hyperbolic system of partial differential equations. The equations for the characteristic surfaces and the compatibility equations applicable along these surfaces are derived. The characteristic surfaces are the stream surfaces, which are surfaces composed of streamlines, and the wave surfaces, which are surfaces tangent to a Mach conoid. The compatibility equations are expressed as directional derivatives along streamlines and bicharacteristics, which are the lines of tangency between a wave surface and a Mach conoid.

311. PAYNTER, G. C.: **Current status of inlet flow prediction methods**. AD-A111784 1981. 82N26311

The increasing availability of large computers, advances in numerical fluid mechanics, and the rapidly escalating cost of wind tunnel testing are responsible for a trend toward the use of parametric analysis rather than parametric testing to support the design of inlet systems. With an emphasis on the transonic and supersonic speed regimes, current approaches to inlet flow analysis are discussed in the context of the inlet design process. Results from typical procedures now under development for supersonic inlet flows are presented along with a discussion of the advantages and disadvantages of each for design. The requirements for experimental validation of a procedure and analysis problem areas are reviewed. Recent developments which may lead to an improved inlet flow analysis capability are discussed.

312. ANDERSON, B. H.; TOWNE, C. E.: **Numerical simulation of supersonic inlets using a three-dimensional viscous flow analysis**. AIAA PAPER 80-0384 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 15 p. 80A20969

A three-dimensional fully viscous computer analysis, which retains the viscous nature of the Navier-Stokes equations, was evaluated to determine its usefulness in the design of supersonic inlets. This procedure takes advantage of physical approximations to limit the high computer time and storage associated with complete

Navier-Stokes solutions. Computed results are presented for a Mach 3.0 supersonic inlet with bleed and a Mach 7.4 hypersonic inlet. Good agreement was obtained between theory and data for both inlets. Results of a mesh sensitivity study are also shown.

313. BIRINGEN, S.; CHAUSSEE, D. S.; MCMILLAN, O. J.: **Calculation of inlet flow fields by an implicit technique**. AIAA PAPER 80-0031 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 9 p. 80A23928

Two-dimensional inlet flow fields in a supersonic free stream are calculated by an implicit, shock-capturing, finite-difference method. The Euler equations are subjected to a general curvilinear transformation and a body-fitted coordinate system is employed. The method is used to solve supercritical, critical, and subcritical flow fields which are simulated by prescribing appropriate conditions at the inlet outflow boundary. Results are presented for a drooped-cowl inlet.

314. BUGGELN, R. C.; MCDONALD, H.; KRESKOVSKY, J. P.; LEVY, R.: **Computation of three-dimensional viscous supersonic flow in inlets.**: AIAA PAPER 80-0194 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 12 p. 80A23941

A new approach has been developed for the computation of the three-dimensional viscous supersonic flow with embedded subsonic regions adjacent to solid boundaries and is applied to a mixed-compression supersonic inlet typical of current designs. The approach uses a reduced form of the three-dimensional Navier-Stokes equations so that the resultant equations can be treated as an initial boundary value problem and thus be solved by non-iterative forward marching in space. The numerical procedure utilizes an efficient consistently-split linearized block implicit technique to solve the finite difference analogues to the set of governing partial differential equations.

315. SPRADLEY, L. W.; STALNAKER, J. F.; RATLIFF, A. W.: **Hyperbolic/parabolic development for the GIM-STAR code.** NASA-CR-3369 LMSC-HREC-TR-D697882 1980. 81N16416

Flow fields in supersonic inlet configurations were computed using the elliptic GIM code on the STAR computer. Spillage flow under the lower cowl was calculated to be 33% of the incoming stream. The shock/boundary layer interaction on the upper propulsive surface was computed including separation. All shocks produced by the flow system were captured. Linearized block implicit (LBI) schemes were examined to determine their application to the GIM code. Pure explicit methods have stability limitations and fully implicit schemes are inherently inefficient; however, LBI schemes show promise as an effective compromise. A quasiparabolic version of the GIM code was developed using elastical parabolized Navier-Stokes methods combined with quasitime relaxation. This scheme is referred to as quasiparabolic although it applies equally well to hyperbolic supersonic inviscid flows. Second order windward differences are used in the marching coordinate and either explicit or linear block implicit time relaxation can be incorporated.

316. VINOGRADOV, V. A.; DUGANOV, V. V.: **Calculation of the flow in a supersonic air intake with allowance for the boundary layer on the fairings.** TsAGI, Uchenye Zapiski, vol. 10, no. 5, 1979, p. 29-34. In Russian. 1979. 80A46847

A straight-through method is proposed for calculating supersonic flows in plane and axisymmetric air intakes with allowance for the boundary layer. Calculations are carried out for an ideal gas, making corrections for the displacement thickness. Some numerical results for freestream Mach numbers in the range from 3 to 8 are given.

317. ANDERSON, B. H.; BISHOP, A. R.; TASSA, Y.; RESHOTKO, E.: **Interaction analysis of viscous flow in supersonic inlets.** In its Inlet Workshop, p 212-228 (See 86N72197 18-01) 1977 86N72211

2.11 DISTORTION, DYNAMICS, AND STABILITY

318. PORDAL, H. S.; KHOSLA, P. K.; RUBIN, S. G.: **A flux-split solution procedure for unsteady inlet flows.** AIAA PAPER 90-0585. AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 9 p. 1990. 90A26967

The unstart and restart of an axisymmetric inlet is investigated using a flux-split procedure applied to the Euler and Reduced Navier Stokes (RNS) equations. A time consistent direct sparse matrix solver is applied to compute the transient flow field both internal and external

to the inlet. Time varying oblique and normal shocks are captured. The code is quite general and is applicable for subsonic, transonic and supersonic free streams. The current analysis is concerned with supersonic flight conditions.

319. KROHN, E. O.; TRIESCH, K.: **Investigation of Ferri instability in supersonic inlets.** ESA-TT-978 DFVLR-FB-85-53 ETN-87-98825 1986. 87N14289

Ferri instability, caused by the inflow of a discontinuity surface (slipline) in the inlet was studied. A criterion for the appearance of the Ferri instability was derived. Flat inlets are most, and semirotation symmetric inlet the least, sensitive to Ferri instability. Means to avoid the instability are discussed. Strength and penetration depth of the slipline play a role in triggering the instability, although this role is not clarified.

320. DEESE, J. E.; AGARWAL, R. K.: **A numerical study of viscous flow in inlets and augmentors.** AIAA PAPER 88-0187 AIAA, Aerospace Sciences Meeting, 26th, Reno, NV, Jan. 11-14, 1988. 8 p. 1988. 88A41092

Flowfields through two-dimensional and axisymmetric inlets and thrust-augmenting ejectors are modeled by use of the thin-layer approximation to the unsteady Reynolds-averaged Navier-Stokes equations. The equations are solved by an explicit multistage Runge-Kutta time-stepping method employing a finite-volume formulation on body-conforming curvilinear grids. Eddy viscosity models are used to describe turbulence effects. Results compare well with experimental data for transonic inlet flows. Improvements in turbulence modeling are needed for better prediction of ejector flowfields.

321. AULEHLA, F.; SCHMITZ, D. M.: **Intake swirl and simplified methods for dynamic pressure distortion assessment.** 1988. 89N16742

It is shown that all supersonic intakes of present combat aircraft produce essentially two types of swirl components of varying magnitude, i.e., bulk and twin swirl. Depending on the sensitivity of the engine towards such disturbances serious engine/intake compatibility problems may arise, for example engine surge and fan vibration. The remedial measures to overcome this problem are described and the solution of fenced intakes selected for Tornado is discussed. A similar problem solution for the Airbus A300 is also presented. The relevance of dynamic total pressure distortion as the prime compatibility parameter for engines without inlet guide vanes is questioned and a proposal for an improved intake disturbance simulation in engine bench tests is made. It is suggested that fully dynamic distortion measurements can be replaced by simplified methods at least in the early stage of a project.

322. SCHWEIKHARD, WILLIAM G.; CHEN, YEN-SEN: **Inlet flow dynamic distortion prediction: Without RMS measurements.** NASA-CR-4060 E-3403 NAS 1.26:4060 1987. 87X10282 DOMESTIC

A two-equation turbulence model, kappa-epsilon model, is used in the prediction of inlet flow dynamic distortion of jet aircraft based on steady state total pressure measurements only. This turbulence model is solved at the compressor face station by using a finite difference scheme. Total pressure rms level of the inlet flow is predicted by the turbulence model. The Melick statistical method is then employed to estimate the peak dynamic distortion based on the analytically predicted total pressure rms level. Results of the prediction compare well with experimental measurements of subsonic, transonic and supersonic inlets under various flight conditions. The present method can be used in the preliminary inlet design phases to reduce the design costs.

323. SCHWEIKHARD, WILLIAM G.; CHEN, YEN-SEN: **Statistical prediction of dynamic distortion of inlet flow using minimum dynamic measurement: An application to the Melick statistical method.** NASA-CR-4059 E-3402 NAS 1.26:4059 1987. 87X10281 DOMESTIC

A simplified explanation of the Melick method of inlet flow dynamic distortion prediction by statistical means has been included. A hypothetic vortex model is used as the basis of the mathematic formulations. The main variables of this model are identified by matching the theoretical total pressure rms ratio with the measured total pressure rms ratio. Data comparisons using HiMAT inlet test data set indicate satisfactory prediction of the dynamic peak distortion for cases with boundary layer control device-vortex generators. A method of the dynamic probe selection, an essential part of this research, has been developed. Validity of the probe selection criteria has been demonstrated by comparing the reduced-probe predictions with the 40- probe predictions. Results indicate that the number of dynamic probes can be reduced to as few as 2 and still retain good accuracy.

324. SCHWEIKHARD, WILLIAM G.; DENNON, STEPHEN R.: **Review and evaluation of recent developments in Melick inlet dynamic flow distortion prediction.** NASA-CR-4061 E-3404 NAS 1.26:4061 1987. 87X10280 DOMESTIC

A brief review of developments in the Melick method of inlet flow dynamic distortion prediction by statistical means is provided. These developments include the general Melick approach with full dynamic measurements, a limited dynamic measurement approach, and a turbulence modelling approach which requires no dynamic rms pressure fluctuation measurements. These modifications are briefly evaluated by comparing predicted and measured peak instantaneous distortion levels from provisional inlet data sets. A nonlinear mean-line following vortex model is proposed and evaluated as a potential criterion for improving the peak instantaneous distortion map generated from the conventional linear vortex of the Melick method. The model is simplified to a series of linear vortex segments which lay along the mean line. Maps generated with this new approach are compared with conventionally generated maps, as well as measured peak instantaneous maps.

325. SCHWEIKHARD, WILLIAM G.; DENNON, STEPHEN R.: **Estimating maximum instantaneous inlet flow distortion from steady-state total pressure measurements with full, limited or no dynamic data: Computer program documentation and user's manual.** NASA-CR-4062 E-3405 NAS 1.26:4062 1987. 87X10339 DOMESTIC

A computer program for statistically predicting peak instantaneous dynamic distortion, given steady-state distortion data and dynamic root mean square pressure fluctuation levels in gas turbine outlets, is presented. The statistical approach utilizes a physical flow model which characterizes inlet flow distortion as due to random vorticity convecting through the inlet duct. Characteristics of a mean vortex are statistically determined to match steady-state distortion data and contour map, as measured by steady-state total pressure probes. The mean vortex characteristics are then intensified according to the mean rms fluctuation level as measured by full or limited high response pressure transducer instrumentation, or as simulated by turbulence modelling, to produce the most probable peak instantaneous distortion level. The computer program utilizes this approach to solve for the dynamic distortion and print the results, including contour maps.

326. GUAN, YAN-SHEN; YARNG, SHIN: **Large amplitude supersonic inlet dynamics.** AIAA PAPER 87-2053 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 8 p. 1987. 87A45382

A mathematical method is presented for analyzing large amplitude supersonic inlet dynamics. It is approximated by the summation of shock component responses under small ramp disturbance which are calculated by applying Willoh's (1968) method for analyzing small amplitude inlet dynamics, but considering the effect of initial values of the shock position for each corresponding ramp. The dynamic responses of the inlet shock position, pressures, etc. are illustrated with sample calculations of NASA 48 cm axisymmetric inlet.

327. MACMILLER, C. J.; HAAGENSON, W. R.: **Unsteady inlet distortion characteristics with the B-1B.** In AGARD Engine Response to Distorted Inflow Conditions, 17 p (See 87N24464 18-07) 1987. 87N24478

An extensive wind tunnel and flight test program was conducted to verify inlet performance and distortion characteristics on the B-1B aircraft. During the course of these investigations, several unsteady, total-pressure disturbances at various discrete frequencies were encountered: (1) inlet duct resonance at low power settings; (2) environmental control system (ECS) precooler duct resonance; and (3) nose gear wake ingestion. This resulted in the need to quantify these effects and assess the impact on engine stability characteristics. As a result, engine control features were modified, and aircraft configuration changes were implemented. Results and findings of these investigations are summarized.

328. SCHWEIKHARD, W. G.; DENNON, S. R.: **Review and evaluation of recent developments in melic inlet dynamic flow distortion prediction and computer program documentation and user's manual estimating maximum instantaneous inlet flow distortion from steady-state total pressure measurements with full, limited, or no dynamic data.** NASA-CR-176765NAS 1.26:176765 1986. 86N24955

A review of the Melick method of inlet flow dynamic distortion prediction by statistical means is provided. These developments include the general Melick approach with full dynamic measurements, a limited dynamic measurement approach, and a turbulence modelling approach which requires no dynamic rms pressure fluctuation measurements. These modifications are

evaluated by comparing predicted and measured peak instantaneous distortion levels from provisional inlet data sets. A nonlinear mean-line following vortex model is proposed and evaluated as a potential criterion for improving the peak instantaneous distortion map generated from the conventional linear vortex of the Melick method. The model is simplified to a series of linear vortex segments which lay along the mean line. Maps generated with this new approach are compared with conventionally generated maps, as well as measured peak instantaneous maps. Inlet data sets include subsonic, transonic, and supersonic inlets under various flight conditions.

329. BION, J. R.: **Characteristics of air intake flow fields and evaluation of the loss of compression surge margin due to flow field distortions in the compressor inlet plane.** ONERA, TP NO. 1986-98 (ICAS, Congress, 15th, London, England, Sept. 7-12, 1986) ONERA, TP, no. 1986-98, 1986, 10 p. 1986. 87A21024

330. BOGAR, T. J.; SAJBEN, M.; KROUTIL, J. C.: **Response of a supersonic inlet to downstream perturbations**. (AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983, AIAA Paper 83-2017) Journal of Propulsion and Power (ISSN 0748-4658), vol. 1, Mar.-Apr. 1985, p. 118-125. Previously cited in issue 16, p. 2296, Accession no. 83A36403. 1985. 85A27093

331. KROHN, E. O.; TRIESCH, K.: **Investigation of Ferri instability in supersonic inlets.** DFVLR-FB-85-53 ISSN-0171-1342 1985. 86N21524

Ferri instability, caused by the inflow of a discontinuity surface (slipline) in the inlet was studied. A criterion for the appearance of the Ferri instability was derived. Flat inlets are the most, and semirotation symmetric inlet the least, sensitive to Ferri instability. Means to avoid the instability are discussed. Strength and penetration depth of the slipline play a role in triggering the instability, although this role is not classified.

332. ADAMS, J. C., JR.; MARTINDALE, W. R.; VARNER, M. O.: **One-dimensional unsteady modeling of supersonic inlet unstart/restart.**: AIAA PAPER 84-0439 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984.34 p. 1984. 84A18094

A quasi-one-dimensional unsteady inviscid analysis of mixed-compression supersonic inlet flow is presented with emphasis on modeling of inlet unstart/restart phenomena. Numerical solution of the governing equations of motion is performed using a computationally efficient shock-capturing split-characteristics algorithm. Inlet unstart is modeled using a mass balance method which relates the expelled normal shock position ahead of the inlet cowl to the amount of spilled mass flow over the inlet housing. Comparison of computed results with experimental data for an axisymmetric inlet at a free-stream Mach number of 2.50 shows quite reasonable agreement over an entire unstart/restart transient which includes centerbody translation and retraction as well as bypass mass flow variations.

333. VARNER, M. O.; MARTINDALE, W. R.; PHARES, W. J.; KNEILE, K. R.; ADAMS, J. C., JR.: **Large perturbation flow field analysis and simulation for supersonic inlets.**: NASA-CR-174676 NAS 1.26:174676 1984. 87N10835

An analysis technique for simulation of supersonic mixed compression inlets with large flow field perturbations is presented. The approach is based upon a quasi-one-dimensional inviscid unsteady formulation which includes engineering models of unstart/restart, bleed, bypass, and geometry effects. Numerical solution of the governing time dependent equations of motion is accomplished through a shock capturing finite difference algorithm, of which five separate approaches are evaluated. Comparison with experimental supersonic wind tunnel data is presented to verify the present approach for a wide range of transient inlet flow conditions.

334. LIU, N.-S.; SHAMROTH, S. J.; MCDONALD, H.: **Dynamic response of shock waves in transonic diffuser and supersonic inlet - An analysis with the Navier-Stokes equations and adaptive grid.** AIAA PAPER 84-1609. American Institute of Aeronautics and Astronautics, Fluid Dynamics, Plasma Dynamics, and Lasers Conference, 17th, Snowmass, CO, June 25-27, 1984. 13 p. 1984. 84A38004

An existing method which solves the multi-dimensional ensemble-averaged compressible time-dependent Navier-Stokes equations in conjunction with mixing length turbulence model and shock capturing technique has been extended to include the shock-tracking adaptive grid systems. The numerical scheme for solving the governing equations is based on a linearized block implicit approach. The effects of grid-motion and grid-distribution on the calculated flow solutions have been studied in relative detail and this is carried out in the context of physically steady, shocked flows computed with non-stationary grids.

Subsequently, the unsteady dynamics of the flows occurring in a supercritically operated transonic diffuser and a mixed compression supersonic inlet have been investigated with the adaptive grid systems by solving the Navier-Stokes equations.

335. DUNN, B. M.; FINK, L. E.: **Parametric test of a simple device for starting an over contracted mixed-compression inlet** (U) 1983. 84X71922 US GOV AGENCIES

336. SCHWEIKHHARD, W. G.; CHEN, Y. S.: **Literature search of publications concerning the prediction of dynamic inlet flow distortion and related topics.**: NASA-CR-3673 NAS 1.26:3673 Feb. 1983 83N18729
Publications prior to March 1981 were surveyed to determine inlet flow dynamic distortion prediction methods and to catalog experimental and analytical information concerning inlet flow dynamic distortion prediction methods and to catalog experimental and analytical information concerning inlet flow dynamics at the engine-inlet interface of conventional aircraft (excluding V/STOL). The sixty-five publications found are briefly summarized and tabulated according to topic and are cross-referenced according to content and nature of the investigation (e.g., predictive, experimental, analytical and types of tests). Three appendices include lists of references, authors, organizations and agencies conducting the studies. Also, selected materials summaries, introductions and conclusions- from the reports are included. Few reports were found covering methods for predicting the probable maximum distortion. The three predictive methods found are those of Melick, Jacox and Motycka. The latter two require extensive high response pressure measurements at the compressor face, while the Melick Technique can function with as few as one or two measurements.

337. BOGAR, T. J.; SAJBEN, M.; KROUTIL, J. C.: **Response of a supersonic inlet to downstream perturbations**. AIAA PAPER 83-2017 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 12 p. 1983. 83A36403

Experimental results are reported for flows in a ramp-type, external compression inlet with a large-aspect-ratio, rectangular cross-section, operated at a freesteam Mach number of 1.84 under the influence of a mechanically generated downstream perturbation. High-speed schlieren and time dependent pressure measurements were employed extensively. In supercritical operation, pressure fluctuations throughout the inlet caused by the excitation varied linearly with the fluctuations at the exit station, even for large exit station amplitudes. In subcritical operation (buzz), the excitation interacted nonlinearly with the naturally present, highly periodic oscillations by either modifying the natural frequency, if the excitation was near a natural harmonic, or by having the excitation modulate the naturally occurring oscillation. In addition, the conditions at the two criticality boundaries were determined as a function of excitation amplitude and frequency.

338. HE, Z.; ZHANG, S.: **Buzz in axisymmetric supersonic inlet and its control**. Acta Aeronautica et Astronautica Sinica, vol. 4, June 1983, p. 73-82. In Chinese, with abstract in English. 1983. 84A12042

Static pressure fluctuations at the cone surface in the throat of an axisymmetric external compression inlet were examined to detect the cause of buzz at the inlet and its control in supersonic conditions. The flow was confined to Mach 1.97 for the tests, which also covered angles of attack of 0 and 12 deg. A sharp pressure fluctuation was found, along with the buzz, when the bow shock separated from the cowl lip at 0 deg. The buzz displayed a characteristic frequency of 43.75 Hz. A buzz frequency of 18.75 Hz was obtained at 12 deg as the bow shock at the lee side of the cone vibrated abruptly and with large amplitude. A specific mass flow permitted through the inlet door eliminated the buzz, stabilized the bow shock, and lowered the amplitude of the pressure fluctuation.

339. ZHANG, K.; YU, S.; PENG, C.: **Effect of a shear layer on stability of an axisymmetric external compression air intake**. Acta Aeronautica et Astronautica Sinica, vol. 4, Sept. 1983, p. 56-62. In Chinese, with abstract in English. 1983. 84A23908

The influence of shear layers of various strengths on the stability of an axisymmetric compression supersonic air intake is studied. Strength is defined as the ratio of total pressure difference between the two sides of a shear layer to the total pressure of the incoming flow. Six central bodies with different cone angles were used to produce shear layers with strengths ranging from 5 to 11 percent of the total pressure of upstream flow inside a free stream wind tunnel with a fixed Mach number of 1.72. Shear layers with less than 10 percent strength were strong enough to cause separation of the boundary layer from the inside surface of the cowl. Shear layers of strength less than 11 percent failed to induce buzz in the axisymmetric intake. The influence of a shear layer depended on its

distance from the lip of the cowl, and was most noticeable at a distance of 10-18 percent of the cowl radius.

340. FINK, L.; OBRIEN, T.; DUNN, B.: **Demonstration and evaluation of the dynamic 'start' inlet concept.** AD-B066240L AFWAL-TR-82-2011 1982. 82X78280 US GOV AGENCIES

341. WEINREICH, H. L.: **One-dimensional nonlinear considerations on supersonic diffuser buzz.** In AGARD Ramjets and Ramrockets for Mil. Appl., 14 p (See 82N32256 22-99) 1982. 82N32262

The fundamental aspects of supersonic intake buzz are discussed. The basic characteristics of the phenomenon are described and its relationship to other unsteady propulsion processes presented. A simplified intake propulsion stability analysis shows the possible influence of diffuser exit Mach number on the stability boundary in comparison to other well-known theories. Nonlinear example calculations using smooth intake pressure recovery curves can illustrate some experimentally observed buzz characteristics. The limits of the theoretical approach are discussed, and the tendencies compared with experimental work.

342. BRY, P.; LAVAL, P.; BILLET, G.: **Distorted flow field in compressor inlet channels.** ASME PAPER 82-GT-125 ONERA, TP NO. 1982-22. American Society of Mechanical Engineers, International Gas Turbine Conference and Exhibit, 27th, London, England, Apr. 18-22, 1982, 10 p. 1982. 82A35355

In the development of new generation fighter aircraft, one of the major problems facing the engine designers is that of predicting the response of turbomachines to inlet flow nonuniformities resulting from critical operation of the aircraft at the outer limits of the flight envelope or atmospheric turbulence or armament firing. In connection with studies of the problem of nonlinear distorted inlet flows, Kimzey (1977) has developed a three-dimensional computer model based on a finite volume method. However, the considered approach seems to rely too heavily on empirical data. Therefore, it appears to be worthwhile to attempt to build a model which would require less data. A description is presented of the first part of such a project, taking into account the development of a three-dimensional computer code for compressible nonlinear unsteady and nonuniform inviscid flow.

343. PERRIER, P.; DELAHAYE, B.; LARUELLE, G.: **An acquisition and analysis system for dynamic tests of air inlets.**: In AGARD Aerodyn. of Power Plant Installation, 14 p (See 82N13065) Aug. 1981 82N13082

Improving the flight domain of combat aircraft leads to operations involving a much large variation of unsteady aerodynamic characteristics at the engine inlet than in the past. To determine if the augmentation will be effectively acceptable for compressors and engines of the future, sufficient knowledge of flows must be acquired. This entails measuring a sufficient number of unsteady flow characteristics; however, the number of measurements made must be limited because of cost as well as because of the possibility of instantaneous or deferred processing. This sequence of measurements takes into account necessary compromises. Cooperation is needed among the aircraft designer, the engine designer, and the research organization so that the work of each can complement that of the others, and an economy of means and a homogeneity of methods for analyzing and interpreting the results is possible.

344. BAUER, C. A.; MACKALL, K. G.; STOLL, F.; TREMBACK, J. W.: **Comparison of flight and wind tunnel model instantaneous distortion data from a mixed-compression inlet (U).** NASA-TM-81362 1981. 82X10037 US GOV AGENCIES AND CONTRACTORS

Data from a mixed-compression inlet on a YF-12C airplane were compared with data obtained from both a full-scale and a one-third- scale wind tunnel model of the same inlet, all operating at nearly identical test conditions for two supersonic Mach numbers. Steady-state and instantaneous values of radial, circumferential, and maximum- minus-minimum distortion descriptors were used for the analysis. Strouhal number scaling techniques were used. Although steady-state distortion levels were sometimes significantly different, a linear relationship existed between the maximum value of instantaneous distortion and the steady-state distortion value. This relationship was independent of both the inlet and the test condition and was valid for both flight and wind tunnel model data. As a result, the maximum in- flight value of instantaneous distortion can be predicted within + or - 10 percent. Inlet turbulence levels on all three inlets agreed well at each test condition. This indicates that the inlet turbulence level measured on wind tunnel models is representative of that measured in flight.

345. LEYNAERT, J.: **Supersonic air-intake buzz.** AD-B051992L FTD-ID(RS)T-1790-79 1980. 81X72853 US GOV AGENCIES

346. OLBOURNE, D. E.: **A simulation of a supersonic intake on a hybrid computer.** Aeronautical Quarterly, vol. 31, Aug. 1980, p. 197-220. 1980. 80A48685

A simulation of the steady-state and dynamic performance of a supersonic powerplant intake is described. A lumped-parameter form of the equations of motion for a compressible fluid is developed. The resulting equations, together with steady-state characteristics, are used to model the performance of a two-dimensional supersonic intake. The model is implemented on the NGTE hybrid computer. The performance, both steady-state and transient, of the resulting real-time simulation has been investigated. Step and frequency responses at two high Mach number flight conditions have been examined and compared with test data. The favorable comparisons obtained demonstrate the validity of the chosen technique.

347. SEIDEL, B. S.; MATWEY, M. D.; ADAMCZYK, J. J.: **Inlet flow distortion in turbomachinery. I - Comparison of theory and experiment in a transonic fan stage. II - A parameter study.** AIAA PAPER 80-1076. AIAA, SAE, and ASME, Joint Propulsion Conference, 16th, Hartford, Conn., June 30-July 2, 1980, AIAA 6 p. 1980. 80A38895

In the present paper, a semi-actuator-disk theory is reviewed that was developed previously for the distorted inflow to a single-stage axial-flow compressor. Flow distortion occurs far upstream; it may be a distortion in stagnation temperature, stagnation pressure, or both. Losses, quasi-steady deviation angles, and reference incidence correlations are included in the analysis, and both subsonic and transonic relative Mach numbers are considered. The theory is compared with measurements made in a transonic fan stage, and a parameter study is carried out to determine the influence of solidity on the attenuation of distortions in stagnation pressure and stagnation temperature.

348. TINDELL, R. H.: **Inlet drag and stability considerations for M/0/ = 2.00 design.** AIAA PAPER 80-1105 AIAA, SAE, and ASME, Joint Propulsion Conference, 16th, Hartford, Conn., June 30-July 2, 1980, AIAA 12 p. 1980. 80A38916

The results of an experimental study to evaluate the drag and low flow stability range of several isolated inlet models are reviewed. Performance comparisons of a rectangular and semiconical model are made and effects of the external compression system, ranging from normal shock to three-shock designs, are discussed and compared to simple theoretical calculations. The study also examines the effectiveness of several means for improving low flow stability, and compares their drag characteristics. An inlet drag coefficient which defines the total installation penalty more completely is introduced.

349. AGNES, A.; BROCHER, E.; MITON, H.: **On the pulsation of a normal shock wave contained in an aerodynamic inlet.** AAAF-NT-79-17 ISBN-2-7170-0544-7 1979. 80N18006

The response of a normal shock wave, located in a nozzle to down stream pressure perturbation was determined. The system for generating pulsations is described, which consists basically of a Hartmann Sprenger tube in which oscillations of up to 30 Khz can be produced. Initial results are presented showing the two frequencies at which the shock wave oscillations are particularly intense. The computation method for the shock wave oscillation amplitude is also discussed.

350. THOMPSON, J. H.; TOMAYKO, M. A.; RUETENIK, J. R.: **Bidcode for computing aircraft engine-inlet response to blast disturbances (U).** AD-C016925 AD-E300462 KA-TR-130 DNA-4548F 1978. 80X71606 US GOV AGENCIES AND CONTRACTORS

351. ZATOLOK, V. V.; IVANYUSHKIN, A. K.; NIKOLAYEV, A. V.: **Interference of a vortex with shock waves in air intake, destruction of vortices.** In its TsAGI Sci. Notes, Vol. 6, No. 2 (AD-B032967L) 297-307 (See 81X72208 05-01) 1978. 81X72224 US GOV AGENCIES

352. MELICK, H. C., JR.; YBARRA, A. H.; BENCZE, D. P.: **Estimating maximum instantaneous distortion from inlet total pressure rms measurements.** AIAA PAPER 78-970 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 15 p. 1978. 78A43525

In the present paper, a new mathematical model of inlet turbulence is developed by application of basic fluid dynamics and statistical concepts.The model provides an understanding of the turbulent inlet flow as well as a

means of describing the flow in quantitative terms. Specifically, the maximum instantaneous distortion produced by inlet unsteady flow can be estimated by the simple measurement of rms data. Practical application of these techniques leads to a data/acquisition/reduction system that is at least one, and maybe two, orders of magnitude less expensive than conventional methods. Each data point can be reduced in terms of the mean strength of the turbulent vortices. By storing these two parameters (that are representative of the unsteady flow with the steady state information), the maximal instantaneous distortion can be reconstructed for other distortion factors at any time subsequent to the test.

353. CAMPBELL, D. H.: **Inlet bleed requirements and predictions.** In NASA Lewis Research Center Inlet Workshop, p 303-310 (See 86N72197 18-01) 1977. 86N72217

354. MELICK, H. C., JR.; YBARRA, A. H.; BENCZE, D. P.: **Estimating maximum instantaneous distortion from inlet total pressure rms and PSD measurements.** AIAA PAPER 75-1213 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 11th, Anaheim, Calif., Sept. 29-Oct. 1, 1975, AIAA 14 p. 1975. 76A10261

An inexpensive method is developed to determine the extreme values of instantaneous inlet distortion. This method also provides insight into the basic mechanics of unsteady inlet flow and the associated engine reaction. The analysis is based on fundamental fluid dynamics and statistical methods to provide an understanding of the turbulent inlet flow and quantitatively relate the rms level and power spectral density (PSD) function of the measured time variant total pressure fluctuations to the strength and size of the low pressure regions. The most probable extreme value of the instantaneous distortion is then synthesized from this information in conjunction with the steady state distortion. Results of the analysis show the extreme values to be dependent upon the steady state distortion, the measured turbulence rms level and PSD function, the time on point, and the engine response characteristics. Analytical projections of instantaneous distortion are presented and compared with data obtained by a conventional, highly time correlated, 40 probe instantaneous pressure measurement system.

355. MAIDEN, D. L.: **Effect of inlet cowl external profile and external stores on the drag of a fighter airplane model with two-dimensional ramp inlets (U).**: NASA-TM-X-2682 L-8501 Feb. 1975 75X10179 US GOV AGENCIES AND CONTRACTORS

The investigation was conducted in the Langley 4-foot supersonic pressure tunnel at a Mach number of 2.01 at angles of attack from about -3 deg to 6 deg and in the Langley 16-foot transonic tunnel at Mach numbers of 0.6, 0.85, and 0.9 at angles of attack generally from -4 deg to 10 deg. Two inlet cowl external profile configurations were studied; one blunt and the other sharp. The effect of the variation of the external profile of the inlet cowl on supersonic and subsonic performance is discussed. In addition to the inlet study, the effect of the installation of externally mounted air-to-air missiles was investigated at Mach 2.01.

356. BARRY, F. W.: **Frequency of supersonic inlet unstarts due to atmospheric turbulence.** NASA-CR-137482 HSER-5838. 1973. 74N22412

A method is developed for relating propulsion system performance penalties due to transient tolerances in inlet throat Mach number and in normal position to the statistical frequency of unstarts of a supersonic inlet caused by atmospheric disturbances. Data on high-altitude atmospheric turbulence, including power spectra and cross spectra of the three gust components and ambient temperature changes and probability of encountering turbulence, are collected and evaluated. General linear analytical models are developed to compute changes in inlet throat Mach number and in normal shock position due to disturbances in inlet geometry, upstream and exit (bypass and engine) flow conditions. The relation of inlet transient tolerances to propulsion system performance is established. A stepwise procedure for relating frequency of inlet unstarts to transient tolerances is presented and applied to representative examples to demonstrate that significant penalties in range may be associated with a low frequency of inlet unstarts.

357. KUTSCHENREUTER, P. H., JR.; MOORE, M. T.; BURNETT, G. A.: **Large scale inlet distortion investigation.** AFFDL-TR-70-20 May 1970 82X73443 US GOV AGENCIES

358. COLE, G. L.; HINGST, W. R.: **Investigation of means for perturbing the flow field in a supersonic wind tunnel.**: NASA-TM-78954 E-9703 1978. 78N27142

The development status of a device for generating atmospheric-type turbulence in supersonic inlet testing is

summarized. Elaborated are desired aerodynamic and actuation capabilities of the device, and the techniques that were considered and their drawbacks.

359. COLE, G. L.: **Atmospheric effects on inlets for supersonic cruise aircraft.**: NASA-TM-X-73647 E-9154 1977. 78N10026

Mixed-compression inlet dynamic behavior in the vicinity of unstart, was simulated and analyzed to investigate time response of an inlet's normal shock to independent disturbances in ambient temperature and pressure and relative velocity (longitudinal gust), with and without inlet controls active. The results indicate that atmospheric disturbances may be more important than internal disturbances in setting inlet controls requirements because they are usually not anticipated and because normal shock response to rapid atmospheric disturbances is not attenuated by the inlet, as it is for engine induced disturbances. However, before inlet control requirements can be fully assessed, more statistics on extreme atmospheric disturbances are needed: Aeronautical Propulsion NASA-SP-381 1975. 75N31068

360. SAUNDERS, B. W.; BISHOP, A. R.; WEBB, J. A., JR.: **Gust generator for a supersonic wind tunnel.**: NASA-TM-X-3120 E-7978 1974. 75N12970

The effectiveness was investigated of a flat plate gust generator that was located in the nozzle throat of the Lewis 10- by 10-foot supersonic wind tunnel. Gust plates were tested at nozzle wall Mach numbers of 3.1, 2.4, and 2.0. Test results show that the flat plate concept may be used as a gust generator for a wind tunnel; however, more extensive investigation is required to completely define its capabilities and limitations. For the single transient data point recorded, a gust amplitude (decrement) of 0.15 in Mach number was obtained. Analysis of these transient data indicates a response with a corner frequency of at least 8 hertz.

361. WASSERBAUER, J. F.; NEUMANN, H. E.; SHAW, R. J.: **Distortion in a full-scale bicone inlet with internal focused compression and 45 percent internal contraction.** : NASA-TM-X-3133 E-7992 1974. 75N11970

The distortion characteristics were investigated at the subsonic diffuser exit of a full-scale, Mach 2.5, axisymmetric, mixed compression inlet. Performance and steady-state distortion characteristics were obtained at zero and maximum angle of attack and during an inlet unstart-restart sequence. For the configuration with no cowl bleed, steady-state distortion P(max)P(min)P(bar) ranged from 0.10 for critical inlet operation at 0 deg angle-of-attack to 0.306 for supercritical inlet operation at 6.84 deg angle-of-attack. Vortex generators provided a 50 percent reduction in steady-state distortion for critical operation. Bleed has a smaller effect on steady-stated distortion.

362. BAUMBICK, R. J.; WALLHAGEN, R. E.; NEINER, G. H.; BATTERTON, P. G.: **Dynamic response of Mach 2.5 axisymmetric inlet with 40 percent supersonic internal area contraction.**: NASA-TM-X-2833 E-7426 1973. 73N27709

Results of experimental tests conducted on a supersonic, mixed compression, axisymmetric inlet are presented. The inlet is designed for operation at Mach 2.5 with a turbofan engine (TF-30). The inlet was terminated with either a choked-orifice plate or a long pipe with variable area choked exit plug. Frequency responses were obtained for selected static pressures in the diffuser. These pressures were selected as potential control signals for terminal shock control. Frequency responses were obtained for the Mach 2 and 2.5 conditions for different terminations. Responses also were obtained with and without cowl bleed. Internal disturbances were produced by sinusoidally varying the inlet overboard bypass doors at frequencies out to 100 hertz.

363. BAUMBICK, R. J.; NEINER, G. H.; COLE, G. L.: **Experimental dynamic response of a two-dimensional, Mach 2.7, mixed compression inlet.**:NASA-TN-D-6957 E-7002 1972. 72N31784

A test program was conducted on a two-dimensional supersonic inlet. Internal disturbances in diffuser exit mass flow were produced by oscillating overboard bypass doors. Open-loop dynamic responses of shock position, throat exit and diffuser exit static pressures are presented. The steady-state and dynamic coupling between ducts were also obtained. The experimental results from the two-dimensional inlet are compared to results from a similar size axisymmetric inlet and also to a transfer function synthesis program.

364. WASSERBAUER, J. F.; WHIPPLE, D. L.: **Experimental investigation of the dynamic response of a supersonic inlet to external and internal disturbances.**: NASA-TM-X-1648 1968. 68N33374

2.12 INLET ACOUSTICS

365. KOBAYASHI, H.; TORISAKI, T.: **Experimental study of flight effect on fan noise. I - A study of inflow control device for simulating in-flight fan noise in static test.**: JSME, Bulletin (ISSN 0021-3764), vol. 29, May 1986, p. 1536-1543. Research supported by the Agency of Industrial Science and Technology. 86A46024

The design, development, and performance of an inflow control device (ICD)which permits (by reducing turbulence) the static-test simulation of flight test conditions when investigating the fan noise of turbofan aircraft engines are reported. Experimental tests on various candidate materials for ana ICD are described along with measurements of the inflow turbulence in flight-test conditions. A prototype 4-m-diameter hemispheric ICD constructed with a combination of perforated plate, wire screen, and 6.3-mm-core aspect-ratio-8 honeycomb is found to reduce the inflow turbulence level to 1 percent at flow velocity 2-5 m/s while lowering acoustic transmission by only 1.0 Db or less.

366. WOODWARD, R. P.; GLASER, F. W.; LUCAS, J. G.: **Low flight speed fan noise from a supersonic inlet.** (AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983, AIAA Paper 83-1415) Journal of Aircraft (ISSN 0021-8669), vol. 21, Sept. 1984, p. 665-672. Previously cited in issue 21, p. 3201, Accession no. 83A45517. 1984. 84A44508

367. WOODWARD, R. P.; GLASER, F. W.; LUCAS, J. G.: **Low flight speed acoustic results for a supersonic inlet with auxiliary inlet doors.** AIAA PAPER 83-1415 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 46 p. 1983. 83A45517

A model supersonic inlet with auxiliary inlet doors and boundary layer bleeds was acoustically tested in simulated low speed flight up to Mach 0.2 in the NASA Lewis 9 x 15 Anechoic Wind Tunnel and statically in the NASA Lewis Anechoic Chamber. A JT8D refan model was used as the noise source. Data were also taken for a CTOL inlet and for an annular inlet with simulated centerbody support struts. Inlet operation with open auxiliary doors increased the blade passage tone by about 10 Db relative to the closed door configuration although noise radiation was primarily through the main inlet rather than the doors. Numerous strong spikes in the noise spectra were associated with the bleed system, and were strongly affected by the centerbody location. The supersonic inlet appeared to suppress multiple pure tone (MPT) generation at the fan source. Inlet length and the presence of support struts were shown not to cause this MPT suppression. Previously announced in STAR as 83N27794

368. WOODWARD, R. P.; GLASER, F. W.; LUCAS, J. G.: **Low flight speed acoustic results for a supersonic inlet with auxiliary inlet doors.** NASA-TM-83411 E-1694 NAS 1.15:83411 1982. 83N27794

A model supersonic inlet with auxiliary inlet doors and bounday layer bleeds was acoustically tested in simulated low speed flight up to Mach 0.2 in the NASA Lewis 9x15 Anechoic Wind Tunnel and statically in the NASA Lewis Anechoic Chamber. A JT8D refan model was used as the noise source. Data were also taken for a CTOL inlet and for an annular inlet with simulated centerbody support struts. Inlet operation with open auxiliary doors increased the blade passage tone by about 10 Db relative to the closed door configuration although noise radiation was primarily through the main inlet rather than the doors. Numerous strong spikes in the noise spectra were associated with the bleed system, and were strongly affected by the centerbody location. The supersonic inlet appeared to suppress multiple pure tone (MPT) generation at the fan source. Inlet length and the presence of support struts were shown not to cause this MPT suppression.

369. BANGERT, L. H.; FELTZ, E. P.; GODBY, L. A.; MILLER, L. D., **Aerodynamic and acoustic behavior of a YF-12 inlet at static conditions.** NASA-CR-163106 LR-29623. 1981. 81N21079

An aeroacoustic test program to determine the cause of YF-12 inlet noise suppression was performed with a YF-12 aircraft at ground static conditions. Data obtained over a wide range of engine speeds and inlet configurations are reported. Acoustic measurements were made in the far field and aerodynamic and acoustic measurements were made inside the inlet. The J-58 test engine was removed from the aircraft and tested separately with a bellmouth inlet. The far field noise level was significantly lower for the YF-12 inlet than for the bellmouth inlet at engine speeds above 5500 rpm. There was no evidence that noise suppression was caused by flow choking. Multiple pure tones were reduced and the spectral peak near the blade passing frequency disappeared in the region of the spike support struts at engine speeds between 6000 and 6600 rpm.

370. BANGERT, L. H.; FELTZ, E. P.; GODBY, L. A.; MILLER, L. D.: **Aerodynamic and acoustic behavior of a YF-12 inlet at static conditions.**: NASA-CR-163106 LR-29623 1981. 81N21079

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371. BANGERT, L. H.; BURCHAM, F. W., JR.; MACKALL, K. G.: **YF-12 inlet suppression of compressor noise - First results.**: AIAA PAPER 80-0099 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 8 p. NASA-supported research. 1980. 80A34537

An aeroacoustic test program was performed with a YF-12 aircraft at ground-static conditions. The objective was to collect acoustic and aerodynamic data that could determine the cause of inlet noise suppression observed earlier. The first results of the test program are presented here. There was no indication that the flow was close to choking. The data indicated significant reduction in sound pressure level (SPL) across the strut and bypass region at frequencies near the blade passing. Far-field data showed that the maximum sound pressure level near the blade-passing frequency was at zero degrees from the inlet centerline.

2.13 INLET CONTROLS

372. ZLENKO, N. A.: **A system of equations of multidimensional regression for describing the field of throttle characteristics of a supersonic intake.** TsAGI, Uchenye Zapiski, vol. 12, no. 1, 1981, p. 43-51. In Russian. 1981. 82A18602

A system of multidimensional regression equations which makes it possible to represent the experimental throttle characteristics of a supersonic intake in a compact and convenient form is derived and tested. The equations make it possible to estimate with experimental accuracy the coefficients of discharge and total-pressure restoration in the entire range of the independent variables. In addition, the proposed approach can be used to develop mathematical methods of experimental design for the testing of supersonic intakes.

373. JOHNSON, P.; EVELYN, G.: **Inlet control system.** In its Advan. Concept Studies for Supersonic Vehicles, 31 p (See 82X10002 01-0) 1981. 82X10011 US GOV AGENCIES AND CONTRACTORS

Technology development for fault-tolerant control of a mixed- compression inlet's geometry to achieve high inlet performance over the operating envelope progressed with simulation activities, control algorithm definitions, and component requirement investigations. Simulation modeling the inlet and engine nonlinearities and complex flow interaction are developed to support the design, synthesis, and cost-effective validation of control algorithms and implementations. Using redundancy management for high reliability and digital processing for high, across-the-envelope performance, control algorithms and implementation were formulated for evaluation. In parallel with control algorithm and implementation evaluations, sensor and actuation performance and interface requirements were prepared to meet the controller objectives. Functional relationships and differential equations were derived for inlet started mode flow dynamics and the inlet actuation system and validated with available experimental data and engineering judgment. Functional diagrams and voltage scale factors were prepared for real-time, hybrid implementation of the analytical models. Prototype software for control mode selection and switching was written as the first step in structured approach.

374. VERSHININ, I. D.; ZLENKO, N. A.: **Secondary processing of experimental throttling characteristics of supersonic air intakes.** TsAGI,Uchenye Zapiski, vol. 11, no. 4, 1980, p. 72-79. In Russian. 1980. 81A35909

An algorithm is presented for the approximation of the experimental throttling characteristics of supersonic air intakes by means of a piecewise-smooth function. A method is developed for estimating the coefficients of the approximation formula and their statistical weights. As an example, the present algorithm is used to perform a

statistical analysis of experimental data for the purpose of determining anomalously large deviations.

375. SANDERS, B. W.: **Turbojet-exhaust-nozzle secondary-airflow pumping as an exit control of an inlet-stability bypass system for a Mach 2.5 axisymmetricmixed-compressioninlet.**: NASA-TP-1532 E-9468 1980. 80N14124

The throat of a Mach 2.5 inlet that was attached to a turbojet engine was fitted with large, porous bleed areas to provide a stability bypass system that would allow a large, stable airflow range. Exhaust-nozzle, secondary-airflow pumping was used as the exit control for the stability bypass airflow. Propulsion system response and stability bypass performance were obtained for several transient airflow disturbances, both internal and external. Internal airflow disturbances included reductions in overboard bypass airflow, power lever angle, and primary-nozzle area, as well as compressor stall. Nozzle secondary pumping as a stability bypass exit control can provide the inlet with a large stability margin with no adverse effects on propulsion system performance.

376. SHAW, R. J.; MITCHELL, G. A.; SANDERS, B. W.: **Distributed educated throat stability bypass to increase the stable airflow range of a Mach 2.5 inlet with 60-percent internal contraction.**: NASA-TM-X-2975 E-7708 1974. 74N25535

The results of an experimental investigation to increase the stable airflow operating range of a supersonic mixed-compression inlet are presented. A distributed educated throat stability-bypass entrance configuration was tested. In terms of diffuser-exit corrected airflow, a large inlet stable airflow range of about 16.1 percent was obtained if a constant pressure was maintained in the bypass plenum. Limited unstart angle of attack data are presented.

377. HAAGENSON, W. R.: **Flight experience with Mach 3 inlet control systems in the XB-70** (U) 1966 84X71465 US GOV AGENCIES

378. GEYSER, L. C.; LEHTINEN, B.; ZELLER, J. R.: **Optimal control of supersonic inlets to minimize unstarts.**: NASA-TN-D-6408 E-6253 1971. 71N30072

379. COLE, G. L.; CROSBY, M. J.; NEINER, G. H.: **Experimental and analytical investigation of fast normal shock position controls for a Mach 2.5 mixed-compression inlet** NASA-TN-D-6382 E-5932 1971. 71N29745

3.0 ENGINES

3.1 GENERAL SURVEYS

380. LOWRIE, B. W.: **Future supersonic transport propulsion optimization.** IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989,Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 203-209. 1990. 91A10968

In order to achieve the optimum cruise performance and airport noise requirements, various variable cycle propulsion systems for a supersonic transport are studied. Fundamental installation requirements show that opportunities to drive the additional flow by turbomachinery can be either front fan, aft fan, or mid fan, and that ejector systems must also be considered. The benefits of these different systems are compared. It is shown that the best projected cruise performance between Mach 2.0 and 2.5 can be achieved with a bypass ratio of 0.8 to 0.5. As a conventional engine of this type produces very high jet velocities at takeoff and adequate silencing is not likely, engines with cycle variability of magnitude much greater than the Olympus 593 are required to swallow greater mass flow and lower jet velocity at takeoff. It is concluded that for an isolated installation the tandem fan engine concept is the best.

381. LOWRIE, B. W.; DENNING, R. M.; GUPTA, P. C.: **The next generation supersonic transport engine: Critical issues.** PNR90576 BLO/163 ETN-89-95556 1989. 90N12605

The design of a successor to the Concorde with a longhaul range of 5500 nautical miles is discussed. The ability of the engine and airframe to produce this range economically is briefly examined. Some offdesign implications of choice of cruise Mach number on matching and subsonic performance are outlined. Environmental requirements which can be controlled or influenced by engine design are discussed and the key issues noted. Consequent requirements for engine cycle variability are defined and two possibilities assessed.

382. MORRIS, SHELBY J., JR.; GEISELHART, KARL A.; COEN, PETER G. **Performance potential of an advanced technology Mach 3 turbojet engine installed on a conceptual high-speed civil transport.** NASA-TM-4144 L-16531 NAS 1.15:4144 1989. 90N10034

The performance of an advanced technology conceptual turbojet optimized for a high-speed civil aircraft is presented. This information represents an estimate of performance of a Mach 3 Brayton (gas turbine) cycle engine optimized for minimum fuel burned at supersonic cruise. This conceptual engine had no noise or environmental constraints imposed upon it. The purpose of this data is to define an upper boundary on the propulsion performance for a conceptual commercial Mach 3 transport design. A comparison is presented demonstrating the impact of the technology proposed for this conceptual engine on the weight and other characteristics of a proposed high-speed civil transport. This comparison indicates that the advanced technology turbojet described could reduce the gross weight of a hypothetical Mach 3 high-speed civil transport design from about 714,000 pounds to about 545,000 pounds. The aircraft with the baseline engine and the aircraft with the advanced technology engine are described.

383. NECHAYEV, YU. N.; KOBELKOV, V. N.; POLEV, A. S.: **Variable-cycle aircraft turbojet engines for multimode aircraft.** AD-B134134L FTD-ID(RS)T-0111-89 1989. 89X73969 US GOV AGENCIES AND CONTRACTORS

384. BARRERE, M.: **Thermodynamics and the future turbine engines.**: ONERA, TP NO. 1989-165 ONERA, TP no. 1989-165, 1989, 16 p. 90A21031

Prospective designs for the propulsion systems for civilian transport aircraft are examined, focusing on the thermodynamic aspects of engine design. The technological challenges of high-speed and orbital flight are discussed. Several propulsion systems are described, including variable cycle systems and hybrid systems. Consideration is given to various combustors, ejectors and augmenters, and several types of fuels used in air breathing propulsion systems.

385. MOXON, JULIAN: **Civil supersonics - Propulsion is the key**. Flight International (ISSN 0015-3710), vol. 135, June 10, 1989, p. 116, 117, 119, 122. 89A45031

Of the three most important environmental problems facing next-generation SST designers, including sonic boom overpressures, Nox pollution of the stratosphere, and airport noise, the latter two are directly addressable by propulsion system design efforts. Attention is presently given to the variable-cycle engine (VCE) efforts of three major aircraft propulsion system manufacturers in the U.S. and Britain; their VCE configurations address the aforementioned problems by varying the amount of turbofan-bypass air from a high flow rate at subsonic speeds to a low one in supersonic cruise. Cooler combustion temperatures reduce NOx, and lower exhaust velocities associated with high-bypass subsonic flow reduce takeoff and landing noise-generating exhaust stream velocities.

386. SAUNDERS, NEAL T.; GLASSMAN, ARTHUR J.: **Turbomachinery technology for high-speed civil flight**. NASA-TM-102092 E-4746 NAS 1.15:102092 1989. 89N24320

NASA Lewis' research and technology efforts applicable to turbomachinery for high-speed flight are discussed. The potential benefits and cycle requirements for advanced variable cycle engines and the supersonic throughflow fan engine for a high-speed civil transport application are presented. The supersonic throughflow fan technology program is discussed. Technology efforts in the basic discipline areas addressing the severe operating conditions associated with high-speed flight turbomachinery are reviewed. Included are examples of work in internal fluid mechanics, high-temperature materials, structural analysis, instrumentation and controls.

387. RUFFLES, PHILIP C.: **Aircraft engines**. IV Exxon Air World (ISSN 0014-5068), vol. 41, no. 1, 1989, p. 36-38. 89A36898

Configurational design and thermodynamic performance gain trends are projected into the next 50 years, in view of the growing interest of aircraft manufacturers in both larger and more efficient high-bypass turbofan engines for subsonic flight and variable cycle engines for supersonic flight. Ceramic and metal-matrix composites are envisioned as the key to achievement of turbine inlet temperatures 300 C higher than the 1400 C which is characteristic of the state-of-the-art, with the requisite high stiffness, strength, and low density. Such fiber-reinforced materials can be readily tailored to furnish greatest strength in a specific direction of loading. Large, low-density engines are critical elements of future 1000-seat aircraft.

388. PRESZ, W. M., JR.; GREITZER, E. M.: **A useful similarity principle for jet engine exhaust system performance.** AIAA PAPER 88-3001 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 11 p. 1988. 88A53122

A similarity principle that facilitates the inference of exhaust systems' performance on the basis of model tests conducted with uniform stagnation temperatures is presented and verified in light of calculations and comparisons with existing data. Potential applications encompass single-flow nozzles, forced mixers, exhaust jets, and ejector nozzles. It is shown that appropriately chosen performance parameters will be similar for both hot flow and cold flow model tests, as long as the initial Mach numbers and total pressures of the flowfield are simulated.

389. SMITH, MARTIN G., JR.: **21st century high speed transport propulsion**. AIAA PAPER 88-2987 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 9 p. 88A44718

The NASA-sponsored High Speed Commercial Transport (HSCT) program's marketing studies have given attention to 300-passenger 6000-n. mi. range supersonic transports operating in the Mach 2-5 range. A key factor in the feasibility of such aircraft is the propulsion system chosen, which in addition to being fuel efficient must be reliable and environmentally acceptable. These studies have recently progressed to the point where the speed regime for the HSCT has been narrowed to Mach 2-plus to Mach 3-plus, using a kerosene-type fuel. A subsequent, more advanced vehicle may use liquid natural gas to cruise at speeds of up to Mach 5.

390. NECHAEV, IULIAN N.; KOBEL'KOV, VIKTOR N.; POLEV, ANATOLII S.: **Variable-cycle turbojet engines for multiple-regime aircraft**. Moscow, Izdatel'stvo Mashinostroenie, 1988, 176 p. In Russian. 1988. 89A38510

The general design and operation of variable-cycle turbojet engines based on mixed-flow bypass engines are reviewed. The discussion covers current trends in the development of powerplants; characteristics of the adjustable elements of variable-cycle turbojet engines; the effective thrust of variable-cycle powerplants; and optimization of powerplants using variable-cycle engines. Control laws for the elements of variable-cycle engines are derived.

391. SMITH, MARTIN G., JR.: **Aircraft engines. II** Exxon Air World, vol. 40, no. 3, 1988, p. 20-22. 89A22926

An account is given of the design features and prospective performance gains of ultrahigh bypass subsonic propulsion configurations and various candidate supersonic commercial aircraft powerplants. The supersonic types, whose enhanced thermodynamic cycle efficiency is considered critical to the economic viability of a second-generation SST, are the variable-cycle engine, the variable stream control engine, the turbine-bypass engine, and the supersonic-throughflow fan. Also noted is the 'turboramjet' concept, which will be applicable to hypersonic aircraft whose airframe structure materials can withstand the severe aerothermodynamic conditions of this flight regime.

392. STEINMETZ, RONALD B.; HINES, BOB G.: **Engine variable geometry effects on commercial supersonic transport development**. AIAA PAPER 87-2101 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 5 p. 87A45406

The widely diversified requirements, such as reduced noise at take off and approach, efficient supersonic cruise, and significant off-design usage of a commercial SST require a propulsion system capable of efficient performance over a wide range of operation. The benefits to the propulsion/aircraft system accruing from engine variable geometry in meeting the requirements can be quantified in terms of aircraft Take Off Gross Weight (TOGW) and Fuel Burn (FB). These FB and TOGW improvements will be evaluated by comparing a fixed-geometry, mixed-flow turbofan to a variable-geometry/cycle engine at a 1990 IOC. Cycle and configurational changes commensurate with Year 2000 IOC will be implemented for the variable geometry/cycle engine. Further, with this engine definition, a variable capture area inlet will be employed so the engine variable geometry can be used to full advantage in aircraft development.

393. BLEVINS, G.; HARTSEL, J.; POWELL, T.: **Variable cycle concepts for high Mach applications.** AIAA PAPER 87-2103 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 11 p. 87A45408

Efforts made by the Air Force to identify advanced propulsion system candidates for high Mach cruise and acceleration applications are described. Propulsion

concepts under consideration include the turbojet, turboramjet, air turboramjet, and a variable cycle turbofan ramjet. An in-house study assessed the feasibility of advanced propulsion systems such as a turbo-scramjet or systems utilizing turbine bypass.

394. MILLER, S. C.: **Future trends - A European view**. International Symposium on Air Breathing Engines, 8th, Cincinnati, OH, June 14-19, 1987, Proceedings (87A46176 20-07). New York, American Institute of Aeronautics and Astronautics, 1987, p. 29-40. 87A46179

A comprehensive aerothermodynamic and economic evaluation of prospective development trends in both military and civilian aircraft air breathing propulsion systems is presented in view of West European requirements and technology base resources. While future trends in civil propulsion will be primarily determined by direct operating cost reduction criteria, those for military aircraft powerplants will be directed toward significant improvements in thrust/weight ratio and compatibility with multirole mission capabilities. Supersonic cruise without recourse to afterburners is an attractive design goal for both military aircraft and civilian SSTs. V/STOL and hypersonic propulsion possibilities are also assessed.

395. ROSEN, ROBERT; FACEY, JOHN R.: **Civil propulsion technology for the next twenty-five years.**: International Symposium on Air Breathing Engines, 8th, Cincinnati, OH, June 14-19, 1987, Proceedings (87A46176 20-07). New York, American Institute of Aeronautics and Astronautics, 1987, p. 3-13. 87A46177

The next twenty-five years will see major advances in civil propulsion technology that will result in completely new aircraft systems for domestic, international, commuter and high-speed transports. These aircraft will include advanced aerodynamic, structural, and avionic technologies resulting in major new system capabilities and economic improvements. Propulsion technologies will include high-speed turboprops in the near term, very high bypass ratio turbofans, high efficiency small engines and advanced cycles utilizing high temperature materials for high-speed propulsion. Key fundamental enabling technologies include increased temperature capability and advanced design methods. Increased temperature capability will be based on improved composite materials such as metal matrix, intermetallics, ceramics, and carbon/carbon as well as advanced heat transfer techniques. Advanced design methods will make use of advances in internal computational fluid mechanics, reacting flow computation, computational structural mechanics and computational chemistry. The combination of advanced enabling technologies, new propulsion concepts and advanced control approaches will provide major improvements in civil aircraft.

396. KAMANIN, L. N.: **A comparative evaluation of certain promising gas-turbine engines of foreign manufacturers in terms of their thrust characteristics and fuel efficiency**. Aviatsionnaia Tekhnika (ISSN 0579-2975), no. 1, 1985, p. 24-27. In Russian. 85A39106

Altitude/speed and thrust characteristics are presented for several gas-turbine engines of foreign manufacturers designed for supersonic cruise aircraft. The engines discussed include a compound Rolls-Royce engine consisting of the main bypass engine and several modular turboramjet engines; the Pratt & Whitney VSCE-502B variable-cycle engine; the VCE-702 turbine bypass engine; and a dual-mode turbofan engine.

397. Advances in aerospace propulsion; Proceedings of the Aerospace Congress and Exposition, Long Beach, CA, October 3-6, 1983. SAE P-131 Congress and Exposition sponsored by the Society of Automotive Engineers. Warrendale, PA, Society of Automotive Engineers, Inc. (SAE P-131), 1983, 155 p. 84A29451

The topics discussed include uncertainty methodology for in-flight thrust determination, backup control for a variable cycle engine, full authority digital control for a small turbine helicopter engine, gas turbine oil systems monitoring, electronic fuel controls for executive jet aircraft, the benefits derivable from combined environmental reliability testing of digital electronic engine controls, and a design approach to integrated flight and propulsion control. Also considered are the aerodynamic effects of movable sidewall nozzle geometry and rotor exit restriction on radial turbine performance, small turbine engine technology development prospects, a composite casting/bonding construction method for an air-cooled, high temperature radial turbine wheel, ceramic applications in gas turbines, the F404 engine reliability program, an F-18 maintainability and reliability program, reliability-oriented design of an air turbine starter, an analytical method for hydraulic pump malfunction data, and the design of a composite outer duct for the F404 engine. For individual items see 84A29452 to 84A29468.

398. HOFFMAN, S.; VARHOLIC, M. C.: **Contracts, grants and funding summary of supersonic cruise research and variable-cycle engine technology programs, 1972 - 1982.** NASA-TM-85650 L-15611 NAS 1.15:85650 1983. 83N33848

NASA-SCAR (AST) program was initiated in 1972 at the direct request of the Executive Office of the White House and Congress following termination of the U.S. SST program. The purpose of SCR was to conduct a focused research and technology program on those technology programs which contributed to the SST termination and, also, to provide an expanded data base for future civil and military supersonic transport aircraft. Funding for the Supersonic Cruise Research (SCR) Program was initiated in fiscal year 1973 and terminated in fiscal year 1981. The program was implemented through contracts and grants with industry, universities, and by in-house investigations at the NASA/OAST centers. The studies included system studies and five disciplines: propulsion, stratospheric emissions impact, materials and structures, aerodynamic performance, and stability and control. The NASA/Lewis Variable-Cycle Engine (VCE) Component Program was initiated in 1976 to augment the SCR program in the area of propulsion. After about 2 years, the title was changed to VCE Technology program. The total number of contractors and grantees on record at the AST office in 1982 was 101 for SCR and 4 for VCE. This paper presents a compilation of all the contracts and grants as well as the funding summaries for both programs.

399. Variable cycle technology propulsion system assessment program TRACE (Technical Report Analysis Condensation Evaluation). AD-B105178L 1982. 87X70773 US GOV AGENCIES AND CONTRACTORS

400. FISHBACH, L. H.; STITT, L. E.; STONE, J. R.; WHITLOW, J. B., JR.: **NASA research in supersonic propulsion: A decade of progress.** NASA-TM-82862 NAS 1.15:82862 1982. 82N26300

A second generation, economically viable, and environmentally acceptable supersonic aircraft is reviewed. Engine selection, testbed experiments, and noise reduction research are described.

401. FISHBACH, L. H.; STITT, L. E.; STONE, J. R.; WHITLOW, J. B., JR.: **NASA research in supersonic propulsion -A decade of progress.** AIAA PAPER 82-1048 AIAA, SAE, and ASME, Joint Propulsion Conference, 18th, Cleveland, OH, June 21-23, 1982, AIAA 23 p. 1982. 82A40417

(Previously announced in STAR as 82N26300)

402. ALLAN, R. D.: **Engine technology study for SCR Supersonic Cruise Research.** NASA-CR-165183 R80AEG576 1980. 80X10236 US GOV AGENCIES AND CONTRACTORS

The effect of selectively adding advanced technology items to a current (1980) technology baseline double bypass variable cycle engine (VCE) is examined and the payoff of the technology items, as measured by airplane takeoff gross weight (TOGW) to fly a 4000 nmi mission, engine reliability, operating cost, and acquisition cost is shown. The effect of technology level on a double bypass VCE is large. The decrease in TOGW for the 4000 nmi mission in changing from current to advanced (1987 to 89) technology at a traded noise level of FAR 36 (1969) -2 EPNdB is 145,000 lb or 16 percent. At the same time, the direct operating cost (DOC) dropped by almost 10 percent, and the engine removal rate dropped by 11 percent; the operating cost went down by 5 percent and the engine acquisition cost showed almost no change. The technology that showed the largest payoff was the increased turbine inlet temperature in combination with the advanced technology turbines. This addition reduced TOGW by 8.7 percent (78,000 lb); reduced DOC by 5.4 percent; improved engine removal rate by 11 percent, and operating cost by 5 percent.

403. ALLAN, R. D.: **Advanced supersonic propulsion studies.** NASA-CR-159338 R80AEG219 1980. 80X10132 US GOV AGENCIES AND CONTRACTORS

Propulsion system support for supersonic cruise research studies were investigated. Computer programs were provided which give engine performance for the GE21/J10 Study B7 and GE21/J11 Study B18 single and double bypass variable cycle engines. An exhaust system design study was also performed for the GE21/J11 Study B18 VCE, which included a 20 shallow chute mechanical suppressor in the outer stream of the coannular exhaust nozzle.

404. ALLAN, R. D.: **Engine technology study for SCR Supersonic Cruise Research.** NASA-CR-165183 R80AEG576 1980. 80X10236 US GOV AGENCIES AND CONTRACTORS

The effect of selectively adding advanced technology items to a current (1980) technology baseline double bypass variable cycle engine (VCE) is examined and the payoff of the technology items, as measured by airplane takeoff gross weight (TOGW) to fly a 4000 nmi mission, engine reliability,operating cost, and acquisition cost is shown. The effect of technology level on a double bypass VCE is large. The decrease in TOGW for the 4000 nmi mission in changing from current to advanced (1987 to 89) technology at a traded noise level of FAR 36 (1969) -2 EPNdB is 145,000 lb or 16 percent. At the same time, the direct operating cost (DOC) dropped by almost 10 percent, and the engine removal rate dropped by 11 percent; the operating cost went down by 5 percent and the engine acquisition cost showed almost no change. The technology that showed the largest payoff was the increased turbine inlet temperature in combination with the advanced technology turbines. This addition reduced TOGW by 8.7 percent (78,000 lb); reduced DOC by 5.4 percent; improved engine removal rate by 11 percent, and operating cost by 5 percent.

405. Technology application study of an advanced supersonic cruise vehicle, phase 7. Advanced supersonic propulsion studies. NASA-CR-159323 PWA-5676-11 1980. 80X10121 <u>US GOV AGENCIES AND CONTRACTORS</u>

The study of supersonic propulsion systems conducted for the McDonnell Douglas Corporation by Pratt and Whitney Aircraft is summarized. This study, referred to as Phase 7, was conducted during the period March 1979 to December 1979. Phase 7 was part of an overall Supersonic Cruise Research(SCR) study sponsored by NASA Langley Research Center, and was a continuation of the integration studies performed by Pratt and Whitney Aircraft for McDonnell Douglas Corporation. The scope of work consisted of conducting propulsion refinement analyses for two Pratt and Whitney Aircraft engine concepts, a Variable Stream Control Engine (VSCE) and a Low Bypass Engine (LBE), establishment of a VSCE automated teleprocessing communications system, and a detailed performance assessment of the Pratt and Whitney Aircraft candidate nozzle exhaust systems for the LBE. The main conclusion derived is that both engine concepts are fully compatible with the advanced supersonic cruise vehicle defined by Douglas.

406. VDOVIAK, J. W.; EBACHER, J. A.: **VCE test bed engine for supersonic cruise research.** In NASA, Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 347-356 (See 81N17981 09-01) 1980. 81N17995

Various design concepts for a variable cycle engine applicable to a supersonic, mixed mission propulsion system which would combine the merits of a turbofan at subsonic operating conditions with those of a turbojet for supersonic operating conditions are briefly examined. In particular the integration of the variable area bypass injector with the core driven (aft fan block) fan stage is discussed and the technical benefits of the configuration are summarized.

407. WESTMORELAND, J. S.: **Progress with variable cycle engines.** In NASA, Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 371-390 (See 81N17981 09-01) 1980. 81N17997

The evaluation of components of an advanced propulsion system for a future supersonic cruise vehicle is discussed. These components, a high performance duct burner for thrust augmentation and a low jet noise coannular exhaust nozzle, are part of the variable stream control engine. An experimental test program involving both isolated component and complete engine tests was conducted for the high performance, low emissions duct burner with excellent results. Nozzle model tests were completed which substantiate the inherent jet noise benefit associated with the unique velocity profile possible of a coannular exhaust nozzle system on a variable stream control engine. Additional nozzle model performance tests have established high thrust efficiency levels at takeoff and supersonic cruise for this nozzle system. Large scale testing of these two critical components is conducted using an F100 engine as the testbed for simulating the variable stream control engine.

408. BROWN, H.: **Multi-variable cycle optimization by gradient methods.** AIAA PAPER 80-0052 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 10 p. 80A18254

Variable-cycle engine (VCE) concepts are being explored as a potential approach for advanced military or commercial supersonic propulsion. This paper represents a progress report on a continuing program for the development of a multivariable cycle optimization capability which can be applied to the problem of VCE control schedule development. The discussion covers conventional nonlinear optimization techniques, the cycle calculation process and its potential effect on the optimization process, two possible approaches to cycle optimization, and examples of their application to VCE control schedule development. Both approaches use internal unbalanced cycle calculations for generating

partial derivatives, frequent derivative updates, and a constrained gradient approach to the optimization process. The first approach employs a numerical integration external to the cycle balance process, while the second approach incorporates the optimization within the internal cycle balance.

409. Technology application study of an advanced supersonic cruise vehicle, phase 6. Advanced supersonic propulsion studies. NASA-CR-159316 PWA-5597-8 1978. 80X10119 US GOV AGENCIES AND CONTRACTORS

Pratt & Whitney Aircraft (P&WA) has conducted a 10 month study program for the McDonnell Douglas Corporation (Douglas) to refine advanced technology propulsion systems for compatibility with a supersonic cruise aircraft concept defined by Douglas. This propulsion integration study program is part of an overall effort to establish an advanced technology base for future supersonic aircraft systems. The work consisted of conducting propulsion refinement analyses and engine/aircraft integration studies for two P&WA engine concepts, a Variable Stream Control Engine (VSCE) and Low Bypass Engine (LBE). The main conclusion derived is that both engine concepts are fully compatible with the advanced supersonic cruise vehicle defined by Douglas. The VSCE-511R study engine, with its unique variable throttle schedule and its adaptability to off design mission requirements,is considered by P&WA to be the most promising engine concept on the basis of weight, overall performance and unsuppressed noise characteristics. The LBE-431R study engine, which incorporates a jet noise suppressor concept defined by Douglas, is considered to be an alternate engine concept.

410. ALLEN, R. D.: **Advanced supersonic propulsion studies.** NASA-CR-159322 R78AEG585 1978. 80X10120 US GOV AGENCIES AND CONTRACTORS

Studies were conducted to provide propulsion system support for the Supersonic Cruise Research Studies. Refined versions of both the single bypass (GE21/J10B7) and double bypass (GE21/J11B18) variable cycle engines were furnished to Douglas. These engines were designed to better match the Douglas airplane and provide improved range at the design gross weight.

411. ALLAN, R. D.: **Advanced supersonic propulsion studies.** NASA-CR-159321 R77AEG586 1977. 80X10129 US GOV AGENCIES AND CONTRACTORS

Supersonic cruise engines matched to the Douglas Mach 2.2 supersonic cruise commercial airplane were supplied in two levels of technology and for different engine cycles. Low bypass turbofan engines were provided for near term (1978-1979) technology and for advanced (1982-1985) technology. These engines were designed to show the improvements provided by advanced technology such as: high turbine inlet temperatures, advanced turbine cooling techniques and advanced materials for both static and rotating parts. In addition to the turbofan engines, a double bypass variable cycle engine, also utilizing advanced (1982-1985) technology was provided to show the benefits to the airplane of an advanced variable cycle engine concept.

412. General Electric company propulsion support for Boeing Commercial Airplane Company SCAR studies. 1977. 80N73147

413. POWERS, A. G.; COLTRIN, R. E.; STITT, L. E.; WEBER, R. J.; E/WHITLOW, J. B., JR.: **Supersonic propulsion technology.** 1979. 80N10216

Propulsion concepts for commercial supersonic transports are discussed. It is concluded that variable cycle engines, together with advanced supersonic inlets and low noise coannular nozzles, provide good operating performance for both supersonic and subsonic flight. In addition, they are reasonably quiet during takeoff and landing and have acceptable exhaust emissions.

414. ALLAN, R. D.: **Advanced supersonic propulsion studies.** : NASA-CR-159321 R77AEG586 1977. 80X10129 US GOV AGENCIES AND CONTRACTORS

Supersonic cruise engines matched to the Douglas Mach 2.2 supersonic cruise commercial airplane were supplied in two levels of technology and for different engine cycles. Low bypass turbofan engines were provided for near term (1978-1979) technology and for advanced (1982-1985) technology. These engines were designed to show the improvements provided by advanced technology such as: high turbine inlet temperatures, advanced turbine cooling techniques and advanced materials for both static and rotating parts. In addition to the turbofan engines, a double bypass variable cycle engine, also utilizing advanced (1982-1985) technology was p show the benefits to the airplane of an advanced variable cycle engine concept.

415. GUINN, W. A.; BALENA, F. J.; CLARK, L. R.; WILLIS, C. **Studies of the impact of advanced technologies applied to supersonic cruise aircraft. Task 4-1: Reduction of supersonic jet noise by over-the-wing engine installation** NASA-CR-132619 LR-26992 1975. 75X10223 US GOV AGENCIES AND CONTRACTORS

Noise shielding of supersonic jets by aircraft structure and acoustic environment of a wing surface scrubbed by a jet were investigated. Tests were conducted in an anechoic chamber. Noise was generated by two inch diameter, circular, convergent-divergent, Mach 1.5 and 2.5 nozzles operating at static cold jet conditions. An arrow wing model of a supersonic cruise aircraft configuration was used to simulate the structure. Spectra and directional plots of unshielded and shielded jets are presented for static operating conditions. These plots indicate that the sound field below an aircraft is significantly altered by structural shielding. However, when flyover time histories are constructed from the static noise fields, peak noise shielding is shown to be approximately 3 db. Peak sideline noise is approximately the same as the nozzle alone noise.

416. FOSS, R. L.; WRIGHT, B. R.; BRAGDON, E. L. **Studies of the impact of advanced technologies applied to supersonic cruise aircraft. Task 4-2: Cruise speed selection study** NASA-CR-13262019 7. 75X10222 US GOV AGENCIES AND CONTRACTORS

A cruise Mach number selection study was undertaken to provide a more in depth investigation of the configuration, operation and economic differences between Mach 2.2 and 2.7 supersonic cruise vehicle (SCV) designs. Results reaffirm earlier studies and indicate that higher cruise speeds offer greater productivity potential and operational flexibility. To achieve these advantages, however, the higher speed airplane must adopt advanced high lift technology improvements and be scheduled aggressively. The technology needed to attain these improvements has been identified. Higher design cruise speeds are more desirable, and the upper limit will be established by temperature considerations and the impact on thermal management and materials selection. Based on the current study results the upper speed boundary that should be used for future technology impact studies is between Mach 2.55 and 2.7.

417. FOSS, R. L.; ZALESKY, R. E. **Studies of the impact of advanced technologies applied to supersonic cruise aircraft: Executive summary** NASA-CR-132618 LR-27054 LR-26089 1975. 75X10221 US GOV AGENCIES AND CONTRACTORS

This report summarizes the work performed during studies of the impact of advanced technologies applied to supersonic cruise aircraft. In Task 1, Technology Forecast and Impact Analysis, a broad aircraft technology forecast was made for the 1975 to 1985 time frame. The impact of these technologies on supersonic cruise vehicles (SCV) was then assessed. Task 2 attempted to define the market potential of an advanced SCV, to point the way to an airplane definition that would yield a viable aircraft, and to conduct sensitivity studies on such an airplane. These studies indicated a design with a cruise speed of Mach 2.7, a range in the 3600 to 4300 n.mi. regime and a capacity between 250 and 300 passengers. Task 3 dealt with concept refinement and engine coordination. Task 4 was comprised of three major subtasks; (1) an acoustic test program; (2) a cruise Mach number study; and (3) a propulsion assessment study.

418. Studies of the impact of advanced technologies applied to supersonic cruise aircraft. Task 4-3: Preliminary propulsion assessment study, appendix A NASA-CR-132621 1975. 75X10287 US GOV AGENCIES AND CONTRACTORS

Specific data comparisons are provided for the various candidate engines. Engine designation is related to the type of engine cycle, physical engine characteristics are described, and size and performance of engine candidates installed on the baseline airplane are compared.

3.2 VARIABLE STREAM CONTROL ENGINES (VSCE)

419. KAMANIN, L. N.: **A comparative evaluation of certain promising gas-turbine engines of foreign manufacturers in terms of their thrust characteristics and fuel efficiency.** Aviatsionnaia Tekhnika (ISSN 0579-2975), no. 1, 1985, p. 24-27. In Russian. 85A39106

Altitude/speed and thrust characteristics are presented for several gas-turbine engines of foreign manufacturers designed for supersonic cruise aircraft. The engines discussed include a compound Rolls-Royce engine consisting of the main bypass engine and several modular turboramjet engines; the Pratt & Whitney VSCE-502B

variable-cycle engine; the VCE-702 turbine bypass engine; and a dual-mode turbofan engine.

420. WESTMORELAND, J. S.; PACKMAN, A. B.: **A successful step toward an advanced supersonic transport engine - Acoustic and emission results from the Pratt and Whitney Aircraft Variable Cycle Engine Program**. AIAA PAPER 81-1593 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 10 p. 81A40968

Test results of the successful NASA acoustic evaluation of the supersonic transport Variable Stream Control Engine (VSCE) are presented. The engine, simulated by the attachment of a three-stage combustor duct burning system with coannular nozzles to a testbed F100 turbofan engine, was found to be environmentally and operationally feasible; with burner emissions being extremely low and duct burner noise not being evident in the far field. Among the topics covered are: (1) VSCE and testbed engine configurations; (2) duct burner configuration and emissions/performance evaluation; (3) system performance goals at sea-level takeoff and supersonic cruise conditions; (4) VSCE acoustic goals and test results, including aft fan component and jet exhaust noise; and (5) estimates of flyover noise.

421. HUNT, R. B.; HOWLETT, R. A.: **Variable stream control engine for advanced supersonic aircraft design update**. In NASA Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 347-370 See 81N17981 09-01) 1980 81N17996

The updating of the engine concept for a second-generation supersonic transport, the variable stream control engine (VSCE), in terms of mechanical design definition and estimated performance is discussed. The design definition reflects technology advancements that improve system efficiency, durability and environments were established. The components unique to the VSCE concept, a high performance duct burner and a low noise coannular nozzle, and the high temperature components are identified as critical technologies. Technology advances for the high temperature components (main combustor and turbines) are also discussed. To address the requirements in this area, the technical approach for undertaking a high temperature validation program is defined. The multi-phased effort would include assorted rig and laboratory tests, then culminate with the demonstration of a flight-type main combustor and single-stage high pressure turbine at operating conditions envisioned for a VSCE.

422. HOWLETT, R. A.; HUNT, R. B.: **VSCE technology definition study**. NASA-CR-159730 PWA-5630-11 1979. 80N10222

Refined design definition of the variable stream control engine (VSCE) concept for advanced supersonic transports is presented. Operating and performance features of the VSCE are discussed, including the engine components, thrust specific fuel consumption, weight, noise, and emission system. A preliminary engine design is presented.

3.3 TURBINE BYPASS ENGINES (TBE)

423. KAMANIN, L. N.: **A comparative evaluation of certain promising gas-turbine engines of foreign manufacturers in terms of their thrust characteristics and fuel efficiency**. Aviatsionnaia Tekhnika (ISSN 0579-2975), no. 1, 1985, p. 24-27. In Russian. 85A39106

Altitude/speed and thrust characteristics are presented for several gas-turbine engines of foreign manufacturers designed for supersonic cruise aircraft. The engines discussed include a compound Rolls-Royce engine consisting of the main bypass engine and several modular turboramjet engines; the Pratt & Whitney VSCE-502B variable-cycle engine; the VCE-702 turbine bypass engine; and a dual-mode turbofan engine.

424. FRANCISCUS, L. C.: **Turbine bypass engine - A new supersonic cruise propulsion concept.** AIAA PAPER 81-1596 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29,1981, AIAA 9 p. 81A40971

Engine performance and mission studies were carried out for a single-spool turbine bypass engine (TBE) concept. Comparisons were made between the TBE, a conventional single-spool turbojet, and the Pratt and Whitney Variable Stream Control Engine (VSCE). The airplane assumed for the study was a Mach 2.32 commercial supersonic transport. The nominal mission was a 4000 nautical mi total range with a 300 nautical mi subsonic cruise leg. The figure of merit was the minimum take off gross weight for the mission. Comparisons of the three engines were also made for the 4000 nautical mi total range with longer subsonic cruise legs.

3.4 DOUBLE BYPASS ENGINES

425. ALLAN, R. D.; HINES, B. G.; WINES, W. L.: **Effect of design temperature on double bypass engines for SCR.** NASA-CR-167854NAS 1.26:167854 R82AEB225 1982. 82X10342 US GOV AGENCIES AND CONTRACTORS

NASA is engaged in a study of the application of advanced technology to long range, supersonic, commercial transport aircraft under the Supersonic Cruise Research (SCR) Program. As part of this study, General Electric has defined and refined variable cycle engine (VCE) concepts that meet the performance and environmental requirements for an advanced, supersonic cruise vehicle. Studies have shown that the double bypass VCE with an oversize front block fan and outer stream mechanical suppressors can meet low noise goals. The technology utilized for most of these engines is considered advanced technology which will be available to start engine development programs in the late 1980's. Component efficiencies, materials, turbine temperatures, and cooling techniques are all effected by the selected technology levels. This current study effort (NASA Contract NAS3-22749) examines the effect of varying the turbine inlet temperature of the cycle from 1427 to 1649 C (2600 to 3000 F) and shows the effect of these temperature levels, as measured by airplane takeoff gross weight to fly a 7408 km (4000 nmi) mission), and by engine operating and acquisition cost. At each temperature level, a parametric cycle study was performed to select the best bypass ratio, fan pressure ratio, and overall pressure ratio.

426. VDOVIAK, J.: **VCE testbed engine system aero/acoustic test. Exhibit C: Definition study for variable cycle testbed engine and associated test program.** NASA-CR-165542 NAS 1.26:165542 R82AEB407 1982. 82X10341 US GOV AGENCIES AND CONTRACTORS

A YJ101 Variable-Cycle Engine (VCE) test was conducted as part of a multiphase, multiyear GE/NASA program to demonstrate key technology features desirable for an advanced supersonic transport application. This testbed engine was an extensively modified version of the Early Acoustic Test VCE and featured a close coupled, rear block, Core Driven Fan Stage (CDFS). Over 100 hours of testing were conducted, and the CDFS concept was validated both from the aerodynamic and the aeromechanical aspects. Due to the complexity, scope, and uniqueness of the core-drive concept, the test phase was conducted in two sequential steps. An evaluation of the CDFS design integration with the core engine was successfully accomplished in 58 hours of testing in a ram test facility, during which the front-block fan conditions were simulated. This testing verified the matching characteristics of the CDFS with the core engine and also determined the variable-stator geometry for the ensuing full-engine test. The testbed VCE, including the double-bypass features, was built combining the core vehicle with the fan and low pressure turbine system and a slave variable exhaust system (prior to acoustic testing with the special coannual nozzle configuration). The engine mechanical and aerodynamic characteristics were successfully demonstrated in 43 hours of testing at the outdoor test site.

427. VDOVIAK, J. W.; KNOTT, P. R.; EBACKER, J. J.: **Aerodynamic/acoustic performance of YJ101/double bypass VCE with coannular plug nozzle.** NASA-CR-159869 R80AEG369 1981. 81N17846

Results of a forward Variable Area Bypass Injector test and a Coannular Nozzle test performed on a YJ101 Double Bypass Variable Cycle Engine are reported. These components are intended for use on a Variable Cycle Engine. The forward Variable Area Bypass Injector test demonstrated the mode shifting capability between single and double bypass operation with less than predicted aerodynamic losses in the bypass duct. The acoustic nozzle test demonstrated that coannular noise suppression was between 4 and 6 Pndb in the aft quadrant. The YJ101 VCE equipped with the forward VABI and the coannular exhaust nozzle performed as predicted with exhaust system aerodynamic losses lower than predicted both in single and double bypass modes. Extensive acoustic data were collected including far field, near field, sound separation/ internal probe measurements as Laser Velocimeter traverses.

428. VDOVIAK, J. W.; KNOTT, P. R.; EBACKER, J. J.: **Aerodynamic/acoustic performance of YJ101/double bypass VCE with coannular plug nozzle.** NASA-CR-168039 NAS 1.26:168039 CDR-1 1981. 83X73251 US GOV AGENCIES AND CONTRACTORS

429. ALLAN, R. D.; JOHNSON, J. E.; JOY, W.; BROWN, R. H.; BARRIAL, H. J.: **Engine cycle studies program.** NASA-CR-159500 R80AEG428 1980. 80X10235 US GOV AGENCIES AND CONTRACTORS

A double bypass, variable cycle engine (VCE) used as the propulsion system for a Mach 2.4 cruise supersonic commercial transport was examined to determine: (1) the acoustic and performance payoffs of the high flow mode of the double bypass VCE; (2) possible cycle improvements for noise goals lower than FAR 36, 1969; (3) manufacturing cost, reliability, and maintainability of the VCE compared to other engine concepts; and (4) the performance and economics payoffs of the features used in the double bypass VCE. Acoustic and performance payoffs were evident with unsuppressed and with mechanically suppressed coannular exhaust system. At noise goals down to 104 EPNdB, changes to the baseline VCE cycle improved takeoff gross weight for a design version by up to 4%. The double bypass feature of the VCE provided performance and acoustic flexibility that resulted in lower takeoff gross weight for all noise levels, utilizing unsuppressed coannular nozzle, suppressed coannular nozzle, and single stream fully suppressed nozzle. The manufacturing cost, reliability, and maintainability of the double bypass VCE compares favorably with the simpler concepts studied (within 1 to 5.5%).

3.5 VARIABLE CYCLE ENGINE (VCE)

430. LOWRIE, B. W.: **Future supersonic transport propulsion optimization**. IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989,Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 203-209. 1990. 91A10968

In order to achieve the optimum cruise performance and airport noise requirements, various variable cycle propulsion systems for a supersonic transport are studied. Fundamental installation requirements show that opportunities to drive the additional flow by turbomachinery can be either front fan, aft fan, or mid fan, and that ejector systems must also be considered. The benefits of these different systems are compared. It is shown that the best projected cruise performance between Mach 2.0 and 2.5 can be achieved with a bypass ratio of 0.8 to 0.5. As a conventional engine of this type produces very high jet velocities at takeoff and adequate silencing is not likely, engines with cycle variability of magnitude much greater than the Olympus 593 are required to swallow greater mass flow and lower jet velocity at takeoff. It is concluded that for an isolated installation the tandem fan engine concept is the best.

431. SAUNDERS, NEAL T.; GLASSMAN, ARTHUR J.: **Turbomachinery technology for high-speed civil flight**. NASA-TM-102092 E-4746 NAS 1.15:102092 1989. 89N24320

NASA Lewis' research and technology efforts applicable to turbomachinery for high-speed flight are discussed. The potential benefits and cycle requirements for advanced variable cycle engines and the supersonic throughflow fan engine for a high-speed civil transport application are presented. The supersonic throughflow fan technology program is discussed. Technology efforts in the basic discipline areas addressing the severe operating conditions associated with high-speed flight turbomachinery are reviewed. Included are examples of work in internal fluid mechanics, high-temperature materials, structural analysis, instrumentation and controls.

432. RUFFLES, PHILIP C.: **Aircraft engines.** IV Exxon Air World (ISSN 0014-5068), vol. 41, no. 1, 1989, p. 36-38. 89A36898

Configurational design and thermodynamic performance gain trends are projected into the next 50 years, in view of the growing interest of aircraft manufacturers in both larger and more efficient high-bypass turbofan engines for subsonic flight and variable cycle engines for supersonic flight. Ceramic and metal-matrix composites are envisioned as the key to achievement of turbine inlet temperatures 300 C higher than the 1400 C which is characteristic of the state-of-the-art, with the requisite high stiffness, strength, and low density. Such fiber-reinforced materials can be readily tailored to furnish greatest strength in a specific direction of loading. Large, low-density engines are critical elements of future 1000-seat aircraft.

433. BLEVINS, G.; HARTSEL, J.; POWELL, T.: **Variable cycle concepts for high Mach applications.** AIAA PAPER 87-2103 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 11 p. 87A45408

Efforts made by the Air Force to identify advanced propulsion system candidates for high Mach cruise and acceleration applications are described. Propulsion concepts under consideration include the turbojet, turboramjet, air turboramjet, and a variable cycle turbofan ramjet. An in-house study assessed the feasibility of advanced propulsion systems such as a turbo-scramjet or systems utilizing turbine bypass.

434. ERKINS, GARY M.: **Three stream turbofan-variable cycle engine with integral turbocompressor.** AIAA PAPER 87-2104 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 6 p. 87A45409

A variable cycle turbofan engine featuring an additional bypass stream has been conceptualized. In conjunction with the conventional thrust-producing duct and core streams, the concept features an independent, coannular bypass stream to provide pressurized air for special application aircraft. This 'turbocompressor' stream can be sized to provide much more flow than possible from core engine bleed and without the attendant debit on core performance. Maximum lift power can be developed at hover or low-speed approach with rapid thrust response for control, go-around, or maneuver. In the low-thrust mode, the engine functions mainly as a turbocompressor. The system can quickly transition to high thrust output while simultaneously supplying bleed power for lift.

435. PRASAD, A.; SUNDARARAJAN, V.: **Flat rating concept introduced in the GTX engine.** Defence Science Journal (ISSN 0011-748X), vol. 35, April 1985, p. 163-170. 86A26071

In bypass engines, the loss of thrust increases with increase in the inlet total temperature. The concept of variable cycle, achieved by varying the maximum cycle temperature in order to increase the available dry thrust, is explained, together with its application to the GTX 37-14U engine design. The design principles of the GTX engine, which is a twin spool turbojet with a throttle ratio of 1.13 are briefly described and the engine performance at 288 K and 318 K is compared to that of a conventional design with a throttle ratio of unity. The variable cycle concept is presently recognized in the design of engines for combat aircraft, designed for supersonic cruise at altitude. Graphs of the performance analysis are included.

436. CYRUS, J. D.; WRUBLESKY, T.: **An investigation of a variable cycle engine based on the Garraway concept, U.S. Patent 3,387,457.** AD-B085264L NADC-84013-60 1984. 85X70018 US GOV AGENCIES

437. TURK, P.: **Power for the ATF - GE and P&W prepare for battle.** Interavia (ISSN 0020-5168), vol. 39, Sept. 1984, p. 895, 896. 1984. 84A48516

The Advanced Tactical Fighter (ATF) engine program known as the Joint Advanced Fighter Engine (JAFE) is expected to encourage both Pratt and Whitney and General Electric in the development of advanced aerodynamics and materials, and in the design of more reliable, simpler engines with longer overhaul lives, lower maintenance manhours per flight hours, and reduced fuel consumption. Pratt and Whitney's PW5000 engine concept incorporates a two-dimensional vectored nozzle, a smaller number of compressor and turbine stages, advanced single-crystal blade designs, and possibly ceramic materials in seal areas. General Electric's GE37 is a more advanced aerodynamic concept variable cycle engine which would operate as a high bypass turbofan in subsonic flight, and pass more air through the turbine during supersonic flight.

438. Advances in aerospace propulsion; Proceedings of the Aerospace Congress and Exposition, Long Beach, CA, October 3-6, 1983. SAE P-131 Congress and Exposition sponsored by the Society of Automotive Engineers. Warrendale, PA, Society of Automotive Engineers, Inc. (SAE P-131), 1983, 155 p. 84A29451

The topics discussed include uncertainty methodology for in-flight thrust determination, backup control for a variable cycle engine, full authority digital control for a small turbine helicopter engine, gas turbine oil systems monitoring, electronic fuel controls for executive jet aircraft, the benefits derivable from combined environmental reliability testing of digital electronic engine controls, and a design approach to integrated flight and propulsion control. Also considered are the aerodynamic effects of movable sidewall nozzle geometry and rotor exit restriction on radial turbine performance, small turbine engine technology development prospects, a composite casting/bonding construction method for an air-cooled, high temperature radial turbine wheel, ceramic applications in gas turbines, the F404 engine reliability program, an F-18 maintainability and reliability program, reliability-oriented design of an air turbine starter, an analytical method for hydraulic pump malfunction data, and the design of a composite outer duct for the F404 engine. For individual items see 84A29452 to 84A29468.

439. Variable cycle technology propulsion system assessment program TRACE (Technical Report Analysis Condensation Evaluation). AD-B105178L 1982. 87X70773 US GOV AGENCIES AND CONTRACTORS

440. ALLAN, R. D.; HINES, B. G.; WINES, W. L.: **Effect of design temperature on double bypass engines for SCR.** NASA-CR-167854NAS 1.26:167854 R82AEB225 1982. 82X10342 US GOV AGENCIES AND CONTRACTORS

NASA is engaged in a study of the application of advanced technology to long range, supersonic, commercial transport aircraft under the Supersonic Cruise Research (SCR) Program. As part of this study, General Electric has defined and refined variable cycle engine (VCE) concepts that meet the performance and environmental requirements for an advanced, supersonic cruise vehicle. Studies have shown that the double bypass VCE with an oversize front block fan and outer stream mechanical suppressors can meet low noise goals. The technology utilized for most of these engines is considered advanced technology which will be available to start engine development programs in the late 1980's. Component efficiencies, materials, turbine temperatures, and cooling techniques are all effected by the selected technology levels. This current study effort (NASA Contract NAS3-22749) examines the effect of varying the turbine inlet temperature of the cycle from 1427 to 1649 C (2600 to 3000 F) and shows the effect of these temperature levels, as measured by airplane takeoff gross weight to fly a 7408 km (4000 nmi) mission), and by engine operating and acquisition cost. At each temperature level, a parametric cycle study was performed to select the best bypass ratio, fan pressure ratio, and overall pressure ratio.

441. VDOVIAK, J.: **VCE testbed engine system aero/acoustic test. Exhibit C: Definition study for variable cycle testbed engine and associated test program.** NASA-CR-165542 NAS 1.26:165542 R82AEB407 1982. 82X10341 US GOV AGENCIES AND CONTRACTORS

A YJ101 Variable-Cycle Engine (VCE) test was conducted as part of a multiphase, multiyear GE/NASA program to demonstrate key technology features desirable for an advanced supersonic transport application. This testbed engine was an extensively modified version of the Early Acoustic Test VCE and featured a close coupled, rear block, Core Driven Fan Stage (CDFS). Over 100 hours of testing were conducted, and the CDFS concept was validated both from the aerodynamic and the aeromechanical aspects. Due to the complexity, scope, and uniqueness of the core-drive concept, the test phase was conducted in two sequential steps. An evaluation of the CDFS design integration with the core engine was successfully accomplished in 58 hours of testing in a ram test facility, during which the front-block fan conditions were simulated. This testing verified the matching characteristics of the CDFS with the core engine and also determined the variable-stator geometry for the ensuing full-engine test. The testbed VCE, including the double-bypass features, was built combining the core vehicle with the fan and low pressure turbine system and a slave variable exhaust system (prior to acoustic testing with the special coannual nozzle configuration). The engine mechanical and aerodynamic characteristics were successfully demonstrated in 43 hours of testing at the outdoor test site.

442. VDOVIAK, J. W.; KNOTT, P. R.; EBACKER, J. J.: **Aerodynamic/acoustic performance of YJ101/double bypass VCE with coannular plug nozzle.** NASA-CR-159869 R80AEG369 1981. 81N17846

Results of a forward Variable Area Bypass Injector test and a Coannular Nozzle test performed on a YJ101 Double Bypass Variable Cycle Engine are reported. These components are intended for use on a Variable Cycle Engine. The forward Variable Area Bypass Injector test demonstrated the mode shifting capability between single and double bypass operation with less than predicted aerodynamic losses in the bypass duct. The acoustic nozzle test demonstrated that coannular noise suppression was between 4 and 6 Pndb in the aft quadrant. The YJ101 VCE equipped with the forward VABI and the coannular exhaust nozzle performed as predicted with exhaust system aerodynamic losses lower than predicted both in single and double bypass modes. Extensive acoustic data were collected including far field, near field, sound separation/ internal probe measurements as Laser Velocimeter traverses.

443. VDOVIAK, J. W.; KNOTT, P. R.; EBACKER, J. J.: **Aerodynamic/acoustic performance of YJ101/double bypass VCE with coannular plug nozzle.** NASA-CR-168039 NAS 1.26:168039 CDR-1 1981. 83X73251 US GOV AGENCIES AND CONTRACTORS

444. WESTMORELAND, J. S.; PACKMAN, A. B.: **A successful step toward an advanced supersonic transport engine - Acoustic and emission results from the Pratt and Whitney Aircraft Variable Cycle Engine Program**. AIAA PAPER 81-1593 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 10 p. 81A40968

Test results of the successful NASA acoustic evaluation of the supersonic transport Variable Stream Control Engine

(VSCE) are presented. The engine, simulated by the attachment of a three-stage combustor duct burning system with coannular nozzles to a testbed F100 turbofan engine, was found to be environmentally and operationally feasible; with burner emissions being extremely low and duct burner noise not being evident in the far field. Among the topics covered are: (1) VSCE and testbed engine configurations; (2) duct burner configuration and emissions/performance evaluation; (3) system performance goals at sea-level takeoff and supersonic cruise conditions; (4) VSCE acoustic goals and test results, including aft fan component and jet exhaust noise; and (5) estimates of flyover noise.

445. ALLAN, R. D.; JOHNSON, J. E.; JOY, W.; BROWN, R. H.; BARRIAL, H. J.: **Engine cycle studies program.** NASA-CR-159500 R80AEG428 1980. 80X10235 US GOV AGENCIES AND CONTRACTORS

A double bypass, variable cycle engine (VCE) used as the propulsion system for a Mach 2.4 cruise supersonic commercial transport was examined to determine: (1) the acoustic and performance payoffs of the high flow mode of the double bypass VCE; (2) possible cycle improvements for noise goals lower than FAR 36, 1969; (3) manufacturing cost, reliability, and maintainability of the VCE compared to other engine concepts; and (4) the performance and economics payoffs of the features used in the double bypass VCE. Acoustic and performance payoffs were evident with unsuppressed and with mechanically suppressed coannular exhaust system. At noise goals down to 104 EPNdB, changes to the baseline VCE cycle improved takeoff gross weight for a design version by up to 4%. The double bypass feature of the VCE provided performance and acoustic flexibility that resulted in lower takeoff gross weight for all noise levels, utilizing unsuppressed coannular nozzle, suppressed coannular nozzle, and single stream fully suppressed nozzle. The manufacturing cost, reliability, and maintainability of the double bypass VCE compares favorably with the simpler concepts studied (within 1 to 5.5%).

446. ALLAN, R. D.: **Engine technology study for SCR Supersonic Cruise Research.** NASA-CR-165183 R80AEG576 1980. 80X10236 US GOV AGENCIES AND CONTRACTORS

The effect of selectively adding advanced technology items to a current (1980) technology baseline double bypass variable cycle engine (VCE) is examined and the payoff of the technology items, as measured by airplane takeoff gross weight (TOGW) to fly a 4000 nmi mission, engine reliability, operating cost, and acquisition cost is shown. The effect of technology level on a double bypass VCE is large. The decrease in TOGW for the 4000 nmi mission in changing from current to advanced (1987 to 89) technology at a traded noise level of FAR 36 (1969) -2 EPNdB is 145,000 lb or 16 percent. At the same time, the direct operating cost (DOC) dropped by almost 10 percent, and the engine removal rate dropped by 11 percent; the operating cost went down by 5 percent and the engine acquisition cost showed almost no change. The technology that showed the largest payoff was the increased turbine inlet temperature in combination with the advanced technology turbines. This addition reduced TOGW by 8.7 percent (78,000 lb); reduced DOC by 5.4 percent; improved engine removal rate by 11 percent, and operating cost by 5 percent.

447. ALLAN, R. D.: **Advanced supersonic propulsion studies**. NASA-CR-159338 R80AEG219 1980. 80X10132 US GOV AGENCIES AND CONTRACTORS

Propulsion system support for supersonic cruise research studies were investigated. Computer programs were provided which give engine performance for the GE21/J10 Study B7 and GE21/J11 Study B18 single and double bypass variable cycle engines. An exhaust system design study was also performed for the GE21/J11 Study B18 VCE, which included a 20 shallow chute mechanical suppressor in the outer stream of the coannular exhaust nozzle.

448. ALLAN, R. D.: **Engine technology study for SCR Supersonic Cruise Research.** NASA-CR-165183 R80AEG576 1980. 80X10236 US GOV AGENCIES AND CONTRACTORS

The effect of selectively adding advanced technology items to a current (1980) technology baseline double bypass variable cycle engine (VCE) is examined and the payoff of the technology items, as measured by airplane takeoff gross weight (TOGW) to fly a 4000 nmi mission, engine reliability,operating cost, and acquisition cost is shown. The effect of technology level on a double bypass VCE is large. The decrease in TOGW for the 4000 nmi mission in changing from current to advanced (1987 to 89) technology at a traded noise level of FAR 36 (1969) -2 EPNdB is 145,000 lb or 16 percent. At the same time, the direct operating cost (DOC) dropped by almost 10 percent, and the engine removal rate dropped by 11 percent; the operating cost went down by 5 percent and the engine acquisition cost showed almost no change. The

technology that showed the largest payoff was the increased turbine inlet temperature in combination with the advanced technology turbines. This addition reduced TOGW by 8.7 percent (78,000 lb); reduced DOC by 5.4 percent; improved engine removal rate by 11 percent, and operating cost by 5 percent.

449. ALLEN, R. D.: **Advanced supersonic propulsion studies.** NASA-CR-159322 R78AEG585 1978. 80X10120 US GOV AGENCIES AND CONTRACTORS

Studies were conducted to provide propulsion system support for the Supersonic Cruise Research Studies. Refined versions of both the single bypass (GE21/J10B7) and double bypass (GE21/J11B18) variable cycle engines were furnished to Douglas. These engines were designed to better match the Douglas airplane and provide improved range at the design gross weight.

450. BROWN, H.: **Multi-variable cycle optimization by gradient methods.** AIAA PAPER 80-0052 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 10 p. 80A18254

Variable-cycle engine (VCE) concepts are being explored as a potential approach for advanced military or commercial supersonic propulsion. This paper represents a progress report on a continuing program for the development of a multivariable cycle optimization capability which can be applied to the problem of VCE control schedule development. The discussion covers conventional nonlinear optimization techniques, the cycle calculation process and its potential effect on the optimization process, two possible approaches to cycle optimization, and examples of their application to VCE control schedule development. Both approaches use internal unbalanced cycle calculations for generating partial derivatives, frequent derivative updates, and a constrained gradient approach to the optimization process. The first approach employs a numerical integration external to the cycle balance process, while the second approach incorporates the optimization within the internal cycle balance.

451. VDOVIAK, J. W.; EBACHER, J. A.: **VCE test bed engine for supersonic cruise research.** In NASA, Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 347-356 (See 81N17981 09-01) 1980. 81N17995

Various design concepts for a variable cycle engine applicable to a supersonic, mixed mission propulsion system which would combine the merits of a turbofan at subsonic operating conditions with those of a turbojet for supersonic operating conditions are briefly examined. In particular the integration of the variable area bypass injector with the core driven (aft fan block) fan stage is discussed and the technical benefits of the configuration are summarized.

452. WESTMORELAND, J. S.: **Progress with variable cycle engines.** In NASA, Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 371-390 (See 81N17981 09-01) 1980. 81N17997

The evaluation of components of an advanced propulsion system for a future supersonic cruise vehicle is discussed. These components, a high performance duct burner for thrust augmentation and a low jet noise coannular exhaust nozzle, are part of the variable stream control engine. An experimental test program involving both isolated component and complete engine tests was conducted for the high performance, low emissions duct burner with excellent results. Nozzle model tests were completed which substantiate the inherent jet noise benefit associated with the unique velocity profile possible of a coannular exhaust nozzle system on a variable stream control engine. Additional nozzle model performance tests have established high thrust efficiency levels at takeoff and supersonic cruise for this nozzle system. Large scale testing of these two critical components is conducted using an F100 engine as the testbed for simulating the variable stream control engine.

453. HUNT, R. B.; HOWLETT, R. A.: **Variable stream control engine for advanced supersonic aircraft design update.** In NASA Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 347-370 See 81N17981 09-01) 1980 81N17996

The updating of the engine concept for a second-generation supersonic transport, the variable stream control engine (VSCE), in terms of mechanical design definition and estimated performance is discussed. The design definition reflects technology advancements that improve system efficiency, durability and environments were established. The components unique to the VSCE concept, a high performance duct burner and a low noise coannular nozzle, and the high temperature components are identified as critical technologies. Technology advances for the high temperature components (main combustor and turbines) are also discussed. To address the requirements in this area, the technical approach for

undertaking a high temperature validation program is defined. The multi-phased effort would include assorted rig and laboratory tests, then culminate with the demonstration of a flight-type main combustor and single-stage high pressure turbine at operating conditions envisioned for a VSCE.

454. POWERS, A. G.; COLTRIN, R. E.; STITT, L. E.; WEBER, R. J.; WHITLOW, J. B., JR.: **Supersonic propulsion technology.** 1979. 80N10216

Propulsion concepts for commercial supersonic transports are discussed. It is concluded that variable cycle engines, together with advanced supersonic inlets and low noise coannular nozzles, provide good operating performance for both supersonic and subsonic flight. In addition, they are reasonably quiet during takeoff and landing and have acceptable exhaust emissions.

455. ALLAN, R. D.: **Advanced supersonic propulsion studies.** : NASA-CR-159321 R77AEG586 1977. 80X10129 US GOV AGENCIES AND CONTRACTORS

Supersonic cruise engines matched to the Douglas Mach 2.2 supersonic cruise commercial airplane were supplied in two levels of technology and for different engine cycles. Low bypass turbofan engines were provided for near term (1978-1979) technology and for advanced (1982-1985) technology. These engines were designed to show the improvements provided by advanced technology such as: high turbine inlet temperatures, advanced turbine cooling techniques and advanced materials for both static and rotating parts. In addition to the turbofan engines, a double bypass variable cycle engine, also utilizing advanced (1982-1985) technology was p show the benefits to the airplane of an advanced variable cycle engine concept.

456. ALLAN, R. D.: **Advanced supersonic propulsion studies.** NASA-CR-159321 R77AEG586 1977. 80X10129 US GOV AGENCIES AND CONTRACTORS

Supersonic cruise engines matched to the Douglas Mach 2.2 supersonic cruise commercial airplane were supplied in two levels of technology and for different engine cycles. Low bypass turbofan engines were provided for near term (1978-1979) technology and for advanced (1982-1985) technology. These engines were designed to show the improvements provided by advanced technology such as: high turbine inlet temperatures, advanced turbine cooling techniques and advanced materials for both static and rotating parts. In addition to the turbofan engines, a double bypass variable cycle engine, also utilizing advanced (1982-1985) technology was provided to show the benefits to the airplane of an advanced variable cycle engine concept.

3.6 ATF ENGINES

457. TURK, P.: **Power for the ATF - GE and P&W prepare for battle.** Interavia (ISSN 0020-5168), vol. 39, Sept. 1984, p. 895, 896. 1984. 84A48516

The Advanced Tactical Fighter (ATF) engine program known as the Joint Advanced Fighter Engine (JAFE) is expected to encourage both Pratt and Whitney and General Electric in the development of advanced aerodynamics and materials, and in the design of more reliable, simpler engines with longer overhaul lives, lower maintenance manhours per flight hours, and reduced fuel consumption. Pratt and Whitney's PW5000 engine concept incorporates a two-dimensional vectored nozzle, a smaller number of compressor and turbine stages, advanced single-crystal blade designs, and possibly ceramic materials in seal areas. General Electric's GE37 is a more advanced aerodynamic concept variable cycle engine which would operate as a high bypass turbofan in subsonic flight, and pass more air through the turbine during supersonic flight.

3.7 SUPERSONIC THROUGHFLOW FAN ENGINES (STFF)

458. FRANCISCUS, LEO C.; MALDONADO, JAIME J.: **Supersonic through-flow fan engine and aircraft mission performance** NASA-TM-102304 E-4991 NAS 1.15:102304 AIAA-89-2139 1989. 90N21038

A study was made to evaluate potential improvement to a commercial supersonic transport by powering it with supersonic through-flow fan turbofan engines. A Mach 3.2 mission was considered. The three supersonic fan engines considered were designed to operate at bypass ratios of 0.25, 0.5, and 0.75 at supersonic cruise. For comparison a turbine bypass turbojet was included in the study. The engines were evaluated on the basis of aircraft takeoff gross weight with a payload of 250 passengers for a fixed range of 5000 N.MI. The installed specific fuel consumption of the supersonic fan engines was 7 to 8

percent lower than that of the turbine bypass engine. The aircraft powered by the supersonic fan engines had takeoff gross weights 9 to 13 percent lower than aircraft powered by turbine bypass engines.

459. BARNHART, PAUL J.: **A preliminary design study of supersonic through-flow fan inlets** AIAA PAPER 88-3075 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 11 p. 1988. 88A53137

From Mach 3.20 cruise propulsion systems, preliminary design studies for two supersonic through-flow fan primary inlets and a single core inlet were undertaken. Method of characteristics and one-dimensional performance techniques were applied to assess the potential improvements supersonic through-flow fan technology has over more conventional systems. A fixed geometry supersonic through-flow fan primary inlet was found to have better performance than a conventional inlet design on the basis of total pressure recovery, air flow, aerodynamic drag and size and weight.

460. CHAMPAGNE, G. A.: **Payoffs for supersonic through flow fan engines in high Mach transports and fighters.** AIAA PAPER 88-2945 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 8 p. 88A44703

A study was conducted to evaluate the potential of incorporating turbofan engines with supersonic through flow fans in a Mach 2.3 civil transport and a Mach 2.5 fighter. In the 762,000 lb commercial transport, the supersonic fan engine provides a 14 percent improvement in range from 5400 to 6140 nm relative to the conventional engine. This range increase is due to a 9 percent reduction in specific fuel consumption and a 31 percent lighter engine/inlet/nacelle. In the Mach 2.5 fighter, the supersonic fan propulsion system provides a 2 percent reduction in takeoff gross weight.

461. BALL, CALVIN L.: **Supersonic throughflow fans for high-speed aircraft.** In its Aeropropulsion '87. Session 6: High-Speed Propulsion Technology, 26 p (See 88N15807 08-07). 1987 88N15810

Increased need for more efficient long-range supersonic flight has revived interest in the supersonic throughflow fan as a possible component for advanced high-speed propulsion systems. A fan that can operate with supersonic inlet axial Mach numbers would reduce the inlet losses incurred in diffusing the flow from supersonic Mach numbers to a subsonic one at the fan face. In addition, the size and weight of an all-supersonic inlet will be substantially lower than those of a conventional inlet. However, the data base for components of this type is practically nonexistent. Therefore, in order to furnish the required information for assessing the potential for this type of fan, the NASA Lewis Research Center has begun a program to design, analyze, build, and test a fan stage that is capable of operating with supersonic axial velocities from inlet to exit. The objectives are to demonstrate the feasibility and potential of supersonic throughflow fans, to gain a fundamental understanding of the flow physics associated with such systems, and to develop an experimental data base for design and analysis code validation. A brief overview of past supersonic throughflow fan activities are provided; the technology needs discussed; the design of a supersonic throughflow fan stage, a facility inlet, and a downstream diffuser described; and the results from the analysis codes used in executing the design are presented. Also presented is an engine concept intended to permit establishing supersonic throughflow within the fan on the runway and maintaining the supersonic throughflow condition within the fan throughout the flight envelope.

462. HAUSMANN, G. F.; BOENIG, F. H.: **The supersonic thruflow turbojet engine concept (U)** 66/09/00 84X71486 <u>US GOV AGENCIES</u>

3.8 OTHER ENGINES

463. SCHWAB, R. R.; HEWITT, F. A.: **Optimization of hybrid propulsion systems.** IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 282-288. Research supported by ESA. 1990. 91A10976

Very high speed transport, with cruise at velocities beyond Mach 3, only yields practical returns in saved time for very long ranges (assuming modest levels of acceleration and deceleration). With the probable levels of airframe lift/drag ratio (5-7) and propulsion system specific fuel consumption from Mach 4 onward, this implies major changes in both fueling and powerplant design from those required for subsonic or even supersonic cruise. Powerplant operating in dual modes, with complex interactions between the variable intakes and nozzles and the core engines and burners seem inevitable. This paper discusses some of the installation and optimization aspects of such powerplant, and highlights

some of the areas requiring major effort before such systems can be considered.

464. HABRARD, ALAIN: **The variable-cycle engine - A solution to the economical and environmental challenge of the future supersonic transport**. IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 211-218. 1990. 91A10969

The optimization of a variable-cycle engine designed for the Mach 2 cruise regime is presented. Principal areas of study include specific fuel consumption; the requirements for noise attenuation on the ground, during takeoff and in cruise; by-pass ratios, the reduction of pollutant emissions; adaptive combustors; and a specific variable-cycle engine concept. A variable-cycle engine would have a cycle different for takeoff and subsonic operation from the supersonic regime. As an example, a double-flow cycle with a bypass ratio of 1 to 2 could be used during takeoff while a single-flow cycle would operate in cruise. The specific variable-cycle engine concept discussed corresponds to a good compromise between engine complexity and air inlet/nozzle complexity. Thus it is possible to achieve necessary installed performance and also meet current noise regulations without resorting to new unproven devices.

465. LAVIEC, G.; GANLEY, G.: **The Rolls Royce/SNECMA Olympus 593 engine operational experience and the lessons learned** IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 73-80. 1990. 91A10958

A review of the 13 years of Concorde engine design and development are presented. Particular attention is devoted to the reliability aspects of this engine running in very severe ambient conditions as compared to a conventional subsonic engine. Specific operational requirements called for an engine to produce sufficient thrust to takeoff with 11 tons of payload for a distance of 3500 nm at Mach 2. To achieve this goal it became necessary to add an afterburner to a conventional twin spool engine and to add a variable secondary nozzle and a thrust reverser. An electronic analog fuel control system was adopted to control the engine to the required turbine inlet temperature appropriate to the thrust required while ensuring that all limitations are not exceeded and that crew handling be minimal. Details and graphs are presented for engine operational experience covering utilization rates, shop visit rates, inflight shutdowns, and the effects of supersonic operations.

466. MORRIS, SHELBY J., GEISELHART, KARL A.(Planning Research Corp., Hampton, VA.), COEN, PETER G.; **Performance potential of an advanced technology Mach 3 turbojet engine installed on a conceptual high-speed civil transport.**: NASA-TM-4144; L-16531; NAS 1.15:4144. Nov. 1989, 31 p. 90N10034

The performance of an advanced technology conceptual turbojet optimized for a high-speed civil aircraft is presented. This information represents an estimated performance of a Mach 3 Brayton (gas turbine) cycle engine optimized for minimum fuel burned at supersonic cruise. This conceptual engine had no noise or environmental constraints imposed upon it. The purpose of this data is to define an upper boundary on the propulsion performance for a conceptual commercial Mach 3 transport design. A comparison is presented demonstrating the impact of technology proposed for this conceptual engine on the weight and other characteristics of a proposed high-speed civil transport. This comparison indicates that the advanced technology turbojet described could reduce the gross weight of a hypothetical Mach 3 high-speed civil transport design from about 714,000 pounds to about 545,000 pounds. The aircraft with the baseline engine and the aircraft with the advanced technology engine are described.

467. SCHWEIGER, F. A.: **Dual cycle turbofan engine.** AIAA PAPER 87-2102 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 9 p. 87A45407

The subsonic Dual Cycle Turbofan Engine is a triple flow, dual shaft, double nozzle, partially-mixed turbofan where certain variability has been employed to greatly enhance its flexibility and performance. This engine utilizes a variable area core nozzle to select nozzle thrust split, control shaft power split, control fan operating line, increase takeoff thrust, and enhance performance. This engine also employs a variable mixer area to give additional performance improvement and to provide a significant amount of reverse thrust with a simple reverser system.

468. ERKINS, GARY M.: **Three stream turbofan-variable cycle engine with integral turbocompressor.** AIAA PAPER 87-2104 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 6 p. 87A45409

A variable cycle turbofan engine featuring an additional bypass stream has been conceptualized. In conjunction with the conventional thrust-producing duct and core streams, the concept features an independent, coannular bypass stream to provide pressurized air for special application aircraft. This 'turbocompressor' stream can be sized to provide much more flow than possible from core engine bleed and without the attendant debit on core performance. Maximum lift power can be developed at hover or low-speed approach with rapid thrust response for control, go-around, or maneuver. In the low-thrust mode, the engine functions mainly as a turbocompressor. The system can quickly transition to high thrust output while simultaneously supplying bleed power for lift.

469. PRASAD, A.; SUNDARARAJAN, V.: **Flat rating concept introduced in the GTX engine.** Defence Science Journal (ISSN 0011-748X), vol. 35, April 1985, p. 163-170. 86A26071

In bypass engines, the loss of thrust increases with increase in the inlet total temperature. The concept of variable cycle, achieved by varying the maximum cycle temperature in order to increase the available dry thrust, is explained, together with its application to the GTX 37-14U engine design. The design principles of the GTX engine, which is a twin spool turbojet with a throttle ratio of 1.13 are briefly described and the engine performance at 288 K and 318 K is compared to that of a conventional design with a throttle ratio of unity. The variable cycle concept is presently recognized in the design of engines for combat aircraft, designed for supersonic cruise at altitude. Graphs of the performance analysis are included.

470. CYRUS, J. D.; WRUBLESKY, T.: **An investigation of a variable cycle engine based on the Garraway concept, U.S. Patent 3,387,457.** AD-B085264L NADC-84013-60 1984. 85X70018 US GOV AGENCIES

471. ROCK, S. M.; BERG, D. F.; FISK, W. S.; PRZYBYLKO, S. J.; SKIRA, C. A.: **Variable cycle engine multivariable control synthesis.** AD-B080669L AFWAL-TR-83-2072 1983. 84X75557 US GOV AGENCIES

472. KUENKLER, H.: **Individual bypass throttling in fighter engines.** AIAA PAPER 82-1285 AIAA, SAE, and ASME, Joint Propulsion Conference, 18th, Cleveland, OH, June 21-23, 1982, AIAA 9 p. 82A35100

It is demonstrated that individual bypass throttling (IBT) by an independent bypass nozzle/throttle device is an attractive means of influencing partload specific fuel consumption characteristics in low bypass ratio turbofan engines, such as those of fighter aircraft, without introducing turbocomponent variable-geometry features. An IBT application is considered in which total engine pressure ratio as well as bypass ratio have been selected with a view to high thrust characteristics and optimum reheat conditions, while the low-partload specific fuel consumption was decreased by means of the IBT feature. The calculated total propulsive weight for both long-loiter and interception fighter missions shows that the more complex construction of a separate bypass nozzle will be compensated by the new engine design's efficiency. An 8% takeoff weight saving was attained by the IBT engine over a conventional design for the two missions considered.

473. GUPTA, P. C.: **Advanced Olympus for the next generation supersonic transport aircraft.** SAE PAPER 800732 Society of Automotive Engineers, International Air Transportation Meeting, Cincinnati, Ohio, May 20-22, 1980, 27 p. 80A49684

The paper summarizes the background studies which have led to the proposal for an advanced Olympus engine, with mechanical noise suppression, to power the next generation supersonic transport aircraft. The recent international collaborative test program on real engine scale ejector suppressors is described and reference is made to other Rolls-Royce experimental work at model scale. The envisaged changes to the design of the in service Concorde engine are outlined and some installation aspects are discussed. It is emphasized that detailed refinement of the engine cycle must depend on the result of aircraft/engine integration and optimization studies.

474. RAMSAY, J. W.: **Potential operating advantages of a variable-area-turbine turbojet.** 1972. 84X71520 NASA PERS. ONLY

3.9 ENGINE CONTROLS

475. KAPASOURIS, P.; ATHANS, M.; SPANG, H. A., III: **Gain-scheduled multivariable control for the GE-21 turbofan engine using the LQG/LTR methodology.**: 1985 American Control Conference, 4th, Boston, MA, June 19-21, 1985, Proceedings. Volume 1 (86A35326 15-63). NewYork, Institute of Electrical and Electronics Engineers, 1985, p. 109-118. Research supported by the General Electric Co. 86A35334

This paper presents a feasibility study related to the design of a global nonlinear multivariable compensator for a model of the GE-21 double-bypass variable cycle jet engine. The nonlinear engine dynamics are linearized at nine distinct operating conditions. Scaling of variable units and Singular Value Decomposition at DC identified the subset of controls and outputs for dynamic control. At each operating condition an LQG/LTR compensator is designed; the parameters of the LQG/LTR compensator are then scheduled to produce a global dynamic compensator. Transient simulations are included to illustrate the characteristics of the nonlinear multivariable control system.

476. KAST, H. B.: **Backup control for variable cycle engine**. SAE PAPER 831475 Advances in aerospace propulsion; Proceedings of the Aerospace Congress and Exposition, Long Beach, CA, October 3-6, 1983 (84A29451 12-07). Warrendale, PA, Society of Automotive Engineers, Inc., 1983, p. 23-28. 84A29454

A backup system is presently defined for a variable cycle aircraft engine's digital primary control system, in order to provide 'get home' capability in the event of primary system failure as well as smooth authority transfer performance, minimum interference during primary digital control operation, engine overspeed and overtemperature protection, and low power loss failure rate. The high level of reliability demonstrated by hydromechanical engine controls in the past is the basis of its selection for the backup system; a failure mode in common with that of the primary digital system in the event of lightning and electromagnetic pulse/interference damage is also there by avoided. Transfer action is initiated in the event of electrical power loss, primary control malfunction, engine overspeed, or pilot command.

477. HUNTER, J. H.: **Advanced digital controller development program, task 1.** AD-A129269 AFWAL-TR-82-2047 DDA-EDR-10431 1982. 83N36034

The objective of this program phase was to develop the specification for a digital controller. This controller would have sufficient computing and I/O capability to control a variable cycle (VCE) single spool (e.g., GMA 200 ATEGG) or two spool (e.g., GMA200 JTDE) configuration. Provision has been made for seven controlled variables. These are: two fuel flows, variable compressor and turbine geometry, two cooling bleed flows, and variable nozzle area. A multivariate control logic structure was selected. Power commands, mode, and ambient conditions are used to estimate the equilibrium operating point. These schedules will then be adjusted to match the engine characteristics using an adaptive control algorithm. Optimal paths between operating points will be computed by a trajectory generator module. A proportional regulator is designed to track small perturbation from this nominal path. The design concept for a digital controller capable of implementing this control logic was developed. This required a specification of the GMA200 fuel control system with particular emphasis on the controller interface. Trade studies were identified and their impact on the control hardware presented. These included actuator selection, fuel system selection, and airflow measurement techniques. Timing and sizing studies were completed. This resulted in the selection of a bit-slice processor (an Am 2901) with 28K EPROM/RAM.

478. BAKER, L.; BRAINARD, W. E.; CURRY, C. E.; DISPARTE, C. P.; DOLNY, L. J.; FLEMING, R. E.; WARNER, D. E.: **Full-authority fault-tolerant electronic engine control system for variable cycle engines.** AD-A121746 DDA-EDR-10895 AFWAL-TR-82-2037 1982. 83N21357

The objective of this program was to develop a design approach for full-authority digital electronic control systems with reliability the primary consideration factor. The approach used in attacking this objective was to identify a baseline full-authority digital electronic control system for and advanced fighter aircraft and then improve on this baseline control with respect to specific goals using redundancy, recovery strategies, and maintenance philosophies. Ambitious goals were established for controls-related mission reliability (2.5 mission aborts per million operating hours), mean time respect to cost and weight in addition to their ability to satisfy the design goals. The baseline control system was modularized to yield identifiable components (pumps, thermocouples, actuators, etc.). For these components, reliability and cost information was accumulated. Many of these configurations were screened with a Markov-based constant failure rate analysis simulation called the

Generalized Reliability and Maintainability Program (GRAMP).

479. PRZYBYLKO, S. J.; ROCK, S. M.: **Evaluation of a multivariable control design on a variable cycle engine simulation.** AIAA PAPER 82-1077. AIAA, SAE, and ASME, Joint Propulsion Conference, 18th, Cleveland, OH, June 21-23, 1982, AIAA 8 p. 82A37682

It is pointed out that aircraft turbine engine propulsion control systems have been the focus of extensive development in recent years. Future engine cycles have been defined and include a significant variable geometry capability to the extent that the thermodynamic engine cycle varies over wide limits. The number of actuated variables was expanded, and resulting control strategies require extension of the current advanced multivariable control methodologies. The present investigation is concerned with the evaluation of a multivariable control designed for the JTDE GE 23 variable cycle engine. Attention is given to a description of the Joint Technology Demonstrator Engine (JTDE), the control requirements,a control structure overview, and the computer simulation and evaluation procedure.

480. STABRYLLA, R. G.: **Performance, life, and operability trade-offs in VCE control logic design.** AD-A127740 R81AEG266 AFWAL-TR-1-2059 1981. 83N77502

481. Performance, life, and operability trade-offs in VCE control logic design. AD-A127503 DDA-EDR-10456 AFWAL-TR-81-2060 1981. 83N77499

482. HURTLE, J. E.; TOOT, P. D.; WANGER, R. P.; VIZZINI, R. W.: **Full authority digital electronic control /FADE - Variable cycle engine demonstration.** AIAA PAPER 81-1498 • AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 8 p. 81A40910

The FADEC program is concerned with the development and the testing of a compact lightweight engine mounted electronic control for turbofan engines. A YJ 101-2x1 variable cycle engine was used in the considered study. In addition to the control functions of earlier turbofan engines, the FADEC control on the variable cycle engine must also control the forward bypass transition valve, the forward variable area bypass injector, and the aft variable area bypass injector, which make possible changes in the bypass ratio of the engine. The FADEC accepts information from 14 external engine sensors or feedback devices, five internally mounted pressure sensors, and a data link with the test site control room. The FADEC utilizes multilayer ceramic modules. The FADEC engine control circuits are partitioned into nine modules. The engine test and the test results are discussed. FADEC demonstrated its capability to perform small and large thrust changes rapidly in all variable cycle engine regimes while maintaining engine component steady state and dynamic limits.

483. MCGLONE, M. E.; DAVIES, W. J.; MILLER, R. J.; SMITH, T. B.; LALA, J. H.; PECK, W. C.: **Full-authority fault-tolerant electronic engine control systems for variable cycle engines.** AD-A115289 PWA-FR-15054 AFWAL-TR-81-2121 1981. 82N30309

This Full Authority Fault Tolerant Electronic Engine Control program (FAFTEEC) was performed under Contract F33615-79-C-2082. The program was a 25-month study to develop design guidance for utilizing redundancy to provide control system architectures capable of very high levels of reliability. The study configured several such systems and evaluated the reliability, cost-of-ownership, weight and implementation. Conclusions of this program were that FAFTEEC goals are obtainable through redundancy and that the resulting system can be obtained at a reasonable cost and weight through dual system advanced technology. Analysis provided by the FAFTEEC allows for the following conclusions to be reached: FAFTEEC goals are reasonable, Redundant systems are required, Single string technology is not cost and weight effective, Coverage of dual systems is extremely important, Coverage via software is complex, costly and will not provide 100 percent coverage, and Dual system technology must be included throughout all system components.

484. VIZZINI, R. W.; TOOT, P. D.: **Full authority digital electronic control application to a variable cycle engine.** SAE PAPER 801203 Society of Automotive Engineers, Aerospace Congress and Exposition, Los Angeles, Calif., Oct. 13-16, 1980, 9 p. 81A34212

This paper describes the design, fabrication, and system bench testing of an advanced Full Authority Digital Electronic Control (FADEC) in preparation for full scale testing on a variable cycle aircraft engine. This control provides all computation and signal-handling capability necessary for the advanced variable cycle engine control task, and is designed to meet challenging reliability, weight, envelope, and life cycle cost objectives. Advanced controller techniques, a unique Failure Indication and

Corrective Action feature which allows continued engine operation without significant performance degradation under multiple fault conditions, and use of large-area multilayer ceramic hybrid modules will be demonstrated for the first time in an on-engine control system.

485. BOYER, R. C.: **Evaluating potential VCE control modes with respect to performance, stability, and engine life utilization.** AIAA PAPER 80-1150 AIAA, SAE, and ASME, Joint Propulsion Conference, 16th, Hartford, Conn., June 30-July 2, 1980, AIAA 7 p. 1980. 80A41189

The modern Variable Cycle Engine permits the control designer great latitude in the development of engine control modes. A method of evaluating potential control modes with the respect to mission performance, engine life, and engine stability during the preliminary design phase of the engine is presented. Control optimization criteria are evaluated with a steady-state engine simulation. Potential control schedules are used to generate steady-state data throughout the flight envelope. Missions are then simulated with the steady-state data and mission time histories are analyzed to determine mechanical and thermal low cycle fatigue and stress rupture effects on critical engine components.

486. Propulsion Controls, 1979. NASA-CP-2137 E-477 1980. 81N12090

487. CORDING, R. W.; OKEEFE, F. J.: **Concurrent development and test of a digital electronic controller with an advanced variable cycle engine**. In AGARD Advan. Control Systems for Aircraft Powerplants, 10 p, (See 80N26306 17-07) 1980 80N26310

The need for high performance systems with wide operating envelopes is discussed with respect to the design of advanced technology variable cycle engines. A program is described in which full authority digital electronic controller is used as a tool in the development of an advanced technology variable cycle engine. The problems and advantages associated with an advanced variable cycle engine are highlighted in a discussion of the control system development.

488. KAST, H. B.: **Backup control for a variable cycle engine.** AD-A094730 R80AEG450 AFAPL-TR-79-2069 1980. 81N19125

The next generation of variable cycle aircraft engines (VCE) will have an increased complexity associated with the number of controlled engine variables, inherent cycle variability, and inlet-engine-exhaust control integration. This level of engine complexity and the expanding integration of aircraft/engine controls causes a commensurate increase in the control system complexity and capacity. Digital electronics has been identified as the only viable means for meeting these significantly more sophisticated requirements of the future VCE. Although recent digital electronic advances promise new levels of reliability, this improvement is offset by the increased circuitry of the more complex control. Especially in the case of the single-engine aircraft, it is recognized that such variable cycle engines should be equipped with a Backup Control for emergency use. The recommended hydromechanical approach has been constructed, calibrated and evaluated in a test cell. These evaluations included transient operation and transfer form the primary control to the backup control and back to primary operation. Successful operation was achieved, providing test hardware which is intended for further validation through on-engine testing.

489. BEATTIE, E. C.: **Design of a multivariable integrated control for a supersonic propulsion system.** In NASA Lewis Research Center Propulsion Controls, 1979, p 35-47 (See 81N12090 03-07) 1980. 81N12094

An inlet/engine/nozzle integrated control mode for the propulsion system of an advanced supersonic commercial aircraft was studied. Results show that integration of these control functions can result in both operational and performance benefits for the propulsion system. For example, this integrated control mode may make it possible to minimize the use of inlet bypass doors for shock position control. This may be of benefit to the aircraft as a result of minimizing: (1) bypass bleed drag effects; (2) perturbations to the aircraft resulting from the side thrust effect of the bypass bleeds; and (3) potential unstarts of the inlet. A conceptual integrated control mode was developed which makes use of many cross coupling paths between inlet and engine control variables and inlet and engine sensed variables. A multivariable control design technique based upon linear quadratic regulator theory was applied to designing the feedback gains for this control to allow a simulation evaluation of the benefits of the integrated control mode.

490. HROCK, S. M.; DEHOFF, R. L.: **Variable cycle engine multivariable control synthesis: Control structure definition.** AD-A078670 AFAPL-TR-79-2043 1979. 80N19117

The variable cycle aircraft turbine engine, GE23-JTDE, represents a prototype of future multimode propulsion plants. It is a sophisticated design of highly variable geometry and multiple control inputs. To control this engine, a large number of engine variables must be sensed. These include engine pressures, temperatures, rotor speeds, and airframe and inlet commands. A controller for this engine must therefore be multivariable (i.e., manipulating large numbers of input and output variables) and multifunctional (i.e., perform, in addition to control logic, data conditioning and fault diagnosis). The development of such a full authority digital electronic controller must utilize demonstrated multivariable design techniques to integrate adequately these complex system functions. A preliminary design of a controller for this variable cycle engine is described. It is implementable on a small digital computer (less than 16K words of storage), and is modular in design (subroutine format). Specific controller functions of transient regulation, steady state regulation, trajectory generation, signal processing, and fault detection and accommodation are incorporated in a way which allows experimentation with different techniques for each function without affecting the overall structure. Promising techniques for implementing each function are discussed.

3.10 COMBUSTORS

491. NGUYEN, HUNG LEE; BITTKER, DAVID A.; NIEDZWIECKI, RICHARD W.: **Investigation of low Nox staged combustor concept in high-speed civil transport engines.** AIAA PAPER 89-2942 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 25th, Monterey, CA, July 10-13, 1989. 14 p. Previously announced in STAR as 89N22606. 1989. 89A47186

Levels of exhaust emissions due to high temperatures in the main combustor of high-speed civil transport (HSCT) engines during supersonic cruise are predicted. These predictions are based on a new combustor design approach:a rich burn/quick quench/lean burn combustor. A two-stage stirred reactor model is used to calculate the combustion efficiency and exhaust emissions of this novel combustor. A propane-air chemical kinetics model is used to simulate the fuel-rich combustion of jet fuel. Predicted engine exhaust emissions are compared with available experimental test data. The effect of HSCT engine operating conditions on the levels of exhaust emissions is also presented. The work described in this paper is a part of the NASA Lewis Research Center High-Speed Civil Transport Low NO(x) Combustor program.

492. NGUYEN, HUNG LEE; BITTKER, DAVID A.; NIEDZWIECKI, RICHARD W. **Investigation of low NOx staged combustor concept in high-speed civil transport engines.** NASA-TM-101977 E-4071 NAS 1.15:101977 AIAA-89-2942 1989. 89N22606

Levels of exhaust emissions due to high temperatures in the main combustor of high-speed civil transport (HSCT) engines during supersonic cruise are predicted. These predictions are based on a new combustor design approach:a rich burn/quick quench/lean burn combustor. A two-stage stirred reactor model is used to calculate the combustion efficiency and exhaust emissions of this novel combustor. A propane-air chemical kinetics model is used to simulate the fuel-rich combustion of jet fuel. Predicted engine exhaust emissions are compared with available experimental test data. The effect of HSCT engine operating conditions on the levels of exhaust emissions is also presented. The work described in this paper is a part of the NASA Lewis Research Center High-Speed Civil Transport Low NO(x) Combustor program.

493. LOHMANN, R. P.; VENINGER, A.: **Aerothermal performance and emissions evaluation of the duct burner in a variable cycle engine testbed.** NASA-CR-165370 PWA-5546-60 1981. 81X10347 US GOV AGENCIES AND CONTRACTORS

An F100 turbofan engine with the conventional afterburner replaced with a duct burner and coannular exhaust nozzle was constructed to provide a large scale substantiation of the advanced technology duct burner and the noise reduction associated with the coannular exhaust. The results of tests conducted on the testbed duct burner generally substantiated those of smaller scale rig tests and provided further evidence of the viability of this duct burner concept. Carbon monoxide and unburned hydrocarbon emissions were low with combustion efficiencies meeting or exceeding the program goal of 99 percent. NO(x) emissions were moderate but in excess of the program goal of 1 gm/kg. The thrust efficiency exceeded the program goal of 94.5 percent at a simulated supersonic cruise condition. Total pressure loss across the duct burner exceeded the program goal but was consistent with that from related small scale rig programs. The duct burner operated satisfactorily and with predictable performance characteristics over the entire range of required operating conditions.

494. LOHMANN, R. P.; HERSHBERGER, R. J.: **Further evaluation of a low emissions high performance duct burner for Variable Cycle Engines (VCE).** NASA-CR-165199 PWA-5513-47 1980. 81X10005 US GOV AGENCIES AND CONTRACTORS

A three stage Vorbix duct burner was evaluated with the objective of introducing refinements to the high power stage that would simplify the configuration and enhance the performance and emissions characteristics. Six additional configurations were evaluated at conditions representative of takeoff, transonic climb and supersonic cruise operation of an advanced supersonic transport engine. Parametric variations of the density, axial location, type and flow size of the fuel injectors in the high power stage and alterations to the rotation sequence of the swirler tubes led to definition of configurations that employed, on a full annular basis, only half the number of high power stage fuel injectors without compromising thrust efficiency and with only a small reduction in combustion efficiency. At the beginning of this phase the total pressure loss was the only performance parameter that exceeded the program goals. The loss mechanism has been identified and in one configuration tested, 40 percent of the excess pressure loss was eliminated without compromising the emissions or thrust efficiency.

495. PLOHMANN, R. P.; MADOR, R. J.; WESTMORELAND, J. S.: **Advanced technology duct burner for variable cycle engines.** AIAA PAPER 80-1201 AIAA, SAE, and ASME, Joint Propulsion Conference, 16th, Hartford, Conn., June 30-July 2, 1980, AIAA 10 p. 1980 80A38966

This paper presents the results of an experimental evaluation conducted to establish the feasibility of an advanced technology duct burner intended to provide low emissions and high performance for fan stream augmentation in advanced supersonic cruise engines. The results indicated that the final configurations of the duct burner satisfied the overall program objective in that acceptable operational characteristics were demonstrated and the majority of the emissions and performance goals were met with those for combustion efficiency and thrust efficiency exceeded by wide margins.

496. DUERR, R. A.; DIEHL, L. A.: **Advanced technology for controlling pollutant emissions from supersonic cruise aircraft.** In NASA Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 535-549 (See 81N17981 09-01) 1980. 81N18004

Gas turbine engine combustor technology for the reduction of pollutant emissions is summarized. Variations of conventional combustion systems and advanced combustor concepts are discussed. Projected results from far term technology efforts aimed at applying the premixed prevaporized and catalytic combustion techniques to aircraft combustion systems indicate a potential for significant reductions in pollutant emission levels.

497. LOHMANN, R. P.; MADOR, R. J.: **Experimental evaluation of a low emissions high performance duct burner for Variable Cycle Engines (VCE).** NASA-CR-159694 PWA-5513-32A 1979. 80N17074

An evaluation was conducted with a three stage Vorbix duct burner to determine the performance and emissions characteristics of the concept and to refine the configuration to provide acceptable durability and operational characteristics for its use in the variable cycle engine (VCE) testbed program. The tests were conducted at representative takeoff, transonic climb, and supersonic cruise inlet conditions for the VSCE-502B study engine. The test stand, the emissions sampling and analysis equipment, and the supporting flow visualization rigs are described. The performance parameters including the fuel-air ratio, the combustion efficiency/exit temperature, thrust efficiency, and gaseous emissions calculations are defined. The test procedures are reviewed and the results are discussed.

4.0 NOZZLES

4.1 GENERAL SURVEYS

498. STITT, LEONARD E.: **Exhaust nozzles for propulsion systems with emphasis on supersonic cruise aircraft.** NASA-RP-1235 E-4789 NAS 1.61:1235 1990. 90N21037

This compendium summarizes the contributions of the NASA-Lewis and its contractors to supersonic exhaust nozzle research from 1963 to 1985. Two major research and technology efforts sponsored this nozzle research work; the U.S. Supersonic Transport (SST) Program and the follow-on Supersonic Cruise Research (SCR) Program. They account for two generations of nozzle technology: the first from 1963 to 1971, and the second from 1971 to 1985.First, the equations used to calculate nozzle thrust are introduced. Then the general types of

nozzles are presented, followed by a discussion of those types proposed for supersonic aircraft. Next, the first-generation nozzles designed specifically for the Boeing SST and the second-generation nozzles designed under the SCR program are separately reviewed and then compared. A chapter on throttle-dependent afterbody drag is included, since drag has a major effect on the off-design performance of supersonic nozzles. A chapter on the performance of supersonic dash nozzles follows, since these nozzles have similar design problems, Finally, the nozzle test facilities used at NASA-Lewis during this nozzle research effort are identified and discussed. These facilities include static test stands, a transonic wind tunnel, and a flying testbed aircraft. A concluding section points to the future: a third generation of nozzles designed for a new era of high speed civil transports to produce even greater advances in performance, to meet new noise rules, and to ensure the continuity of over two decades of NASA research.

499. TUEGEL, D. W.; WALLACE, H. W.; DEJONG, D. R.: **High performance supercruise nozzles.** AD-B133756L AFWAL-TR-88-3090 1989. 89X73576 US GOV AGENCIES AND CONTRACTORS

500. DUSA, D. J.: **High Mach propulsion system installation and exhaust system design considerations.** AIAA PAPER 87-2941 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Saint Louis, MO, Sept. 14-16, 1987. 6 p. 88A14279
The prospects that have emerged for the development of efficient powerplants operating in the Mach 3-6 regime, for both commercial transport aircraft and military aircraft, are presently evaluated in view of the last decade's advancements in aircraft gas turbine engine technology. Attention is given to exhaust nozzle component technology readiness issues associated with the use of such exotic fuels as hydrogen and methane, on the one hand, and the generally far higher operating temperatures that will be encountered, on the other. While turbofan cycles are preferred below Mach 4, a dual-mode turboramjet will be needed for the Mach 4-6 regime.

501. GEIDEL, H. A.: **Improved agility for modern fighter aircraft. II - Thrust vectoring engine nozzles.** International Symposium on Air Breathing Engines, 8th, Cincinnati, OH, June 14-19, 1987, Proceedings (87A46176 20-07). New York, American Institute of Aeronautics and Astronautics, 1987, p. 47-54. 87A46181

A comparison is made of thrust-vectoring axisymmetric and two-dimensional nozzles for different applications. The axisymmetric vectoring nozzle will permit vectoring with moderate weight penalty; by contrast, the two-dimensional nozzle involves extraordinary weight penalty and considerable construction complexity. These difficulties are nevertheless offset by takeoff- and landing-improving thrust vectoring capabilities. Further nozzle development efforts favor weight reduction by means of nonmetallic, highly refractory composite materials.

502. HARDY, J.-M.: **Exhaust system for combat aircraft optimized for supersonic cruise.** L'Aeronautique et l'Astronautique (ISSN 0001-9275), no. 104, 1984, p. 16-28. In French. 84A34172

The Concorde nozzle principle is described together with its calculation methods. Results from an optimization study of the internal structure of the Concorde ejector in supersonic cruise are analyzed, emphasizing the significance of the secondary pressure level in the selection of the primary ejector type and taking into consideration the hot gas effect during interpretation of wind tunnel data. Topics covered include techniques for supersonic cruise optimization; Mirage nozzles; calculations of the primary flow, of the flow in a two-flux ejector (short and long ejectors); the adaptation of the afterbody to subsonic flight conditions; the effect of external parameters on afterbody performance; long ejectors for a primary convergent-divergent nozzle; biconic nozzles; and optimization of the propulsion system.

503. HARDY, J. M.: **Exhaust system for combat aircraft optimized for supersonic cruise.** AD-B080166L FTD- ID(RS)T-1798-83 1984. 84X74520 US GOV AGENCIES

504. BEDIAKO, E. D.; WHITTAKER, R. W.: **SCAR exhaust nozzle test program and analysis.** NASA-CR-166035 NAS 1.26:166035 R82AEB495 1983. 83X10238 US GOV AGENCIES AND CONTRACTORS

A test of single flow annular plug nozzles for supersonic cruise application was conducted in the Langley 16-foot transonic wind tunnel (16'TT). The objectives were as follows: 1. To establish analytical relationship between Gross Thrust Coefficient (CFG) and nozzle aerodynamic and geometric variables. 2. To accumulate a performance data base for supersonic cruise plug nozzles. 3. To determine performance differences between the full and the scalloped shrouds. Thirty-seven configurations were tested ranging in Nozzle Pressure Ratios (NPR) and Mach

numbers of 2-10, and 0-1.2 respectively. Two groups of five of the 37 models were identical except for shroud termination; full shroud for one group and scalloped shroud for the other. A designed experiment technique was utilized to define the model variables and test conditions so that an analytical expression relating Gross Thrust Coefficient to nozzle aerodynamic and geometric variables could be derived.

505. DUSA, D. J.; SPEIR, D. W.; ROWE, R. K.; LEAVITT, L. D.: **Advanced technology exhaust nozzle development.** AIAA PAPER 83-1286 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle,WA, June 27-29, 1983. 17 p. 83A38080

The requirement for greater tactical aircraft operational capabilities has led to increasing research emphasis on the refinement of engine/airframe integration methods and exhaust nozzle flexibility. A major prospective advancement in the development of these capabilities takes the form of multifunctional exhaust nozzle systems with thrust reversal and thrust vectoring features, whose operation will be shared by both airframe and powerplant control systems. Attention is presently given to the two-dimensional convergent-divergent and single expansion ramp nozzle designs, with emphasis on the variable geometry mechanical systems by which they assume cruising flight, vectoring, and thrust reversal operations. The nozzles have been wind tunnel model-tested for the cases of the F-18 fighter and a supersonic cruise configuration concept.

506. SPEIR, D. W.; BLOZY, J. T.: **Internal performance prediction for advanced exhaust systems.** (AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 81-1490.) Journal of Aircraft, vol. 20, Mar. 1983, p. 216-221. 1983. 83A22156

(Previously cited in issue 19, p. 3267, Accession no. 81A40908)

507. ST. JOHN, R. S.; ATKINSON, J. R.; PIERSON, J.; MARSHALL, K. S.: **Exhaust system weight estimation methodology.** AD-B074815L REPT-2-51130/2R-53125 NAPC-PE-61 1982. 84X70859 US GOV AGENCIES

508. HUNT, R. B.; KARDAS, G. E.: **Supersonic cruise nozzle exhaust systems: An aeromechanical design study and improvements to analytical techniques.** NASA-CR-165416 PWA-5550-57 1981. 81X10346 US GOV AGENCIES AND CONTRACTORS

The aeromechanical design definition of supersonic cruise nozzle exhaust systems for the Variable Stream Control Engine and the evaluation, improvement and application of analytical techniques for ejector nozzles are described. Two ejector nozzle systems were defined during the aeromechanical design study; an actuated inlet ejector nozzle and a long variable flap ejector nozzle. Both systems offer potentially significant improvement in subsonic nozzle performance and aircraft range capability relative to nozzle systems tested previously. Two advanced analytical procedures for predicting nozzle performance, the General Supersonic Flow Analysis code and the Supersonic Ejector Nozzle code, were evaluated. Analytical results generated with the Supersonic Ejector Nozzle code showed reasonable agreement with data obtained during previous wind tunnel tests. Based on the evaluation, the Supersonic Ejector Nozzle code was selected for modification and enhancement. The improved code was subsequently used to estimate the performance of the actuated inlet and long variable flap ejector nozzles.

509. SPEIR, D. W.; BLOZY, J. T.: **Development of exhaust nozzle internal performance prediction techniques for advanced aircraft applications.** AIAA PAPER 81-1490 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 11 p. 1981. 81A40908

The development of experimental and theoretical methods for the study and prediction of advanced thrust-vectoring nozzle internal performance, from the 1950s to the present and on to 1990, is described. In addition, a detailed account is given of design and development methods currently being applied to two-dimensional convergent-divergent (CD) and single expansion ramp (SERN) vectorable nozzles. Among the topics covered are (1)the configuration and evaluation of candidate exhaust systems; (2) analytical methods for potential flow and boundary layer analysis; (3) nozzle testing facilities and typical nozzle configurations tested; and (4) nonaxisymmetric nozzle internal performance prediction procedures.

510. BERRIER, B. L.; RE, R. J.: **Investigation of convergent-divergent nozzles applicable to reduced-power supersonic cruise aircraft.** NASA-TP-1766 L-13974 1980. 81N14972

An investigation was conducted of isolated convergent-divergent nozzles to determine the effect of several design

parameters on nozzle performance. Tests were conducted using high pressure air for propulsion simulation at Mach numbers from 0.60 to 2.86 at an angle of attack of 0 deg and at nozzle pressure ratios from jet off to 46.0. Three power settings (dry, partial afterburning, and maximum afterburning), three nozzle lengths, and nozzle expansion ratios from 1.22 to 2.24 were investigated. In addition, the effects of nozzle throat radius and a cusp in the external boattail geometry were studied. The results of this study indicate that, for nozzles operating near design conditions, increasing nozzle length increases nozzle thrust-minus-drag performance. Nozzle throat radius and an external boattail cusp had negligible effects on nozzle drag or internal performance.

511. SCHLOEMER, J. J.; WHITTAKER, R. W.; WOLF, J. P.: **Supersonic cruise vehicle exhaust system study.** NASA-CR-177981 NAS 1.26:177981 R80AEG275 1980. 85X10399 US GOV AGENCIES AND CONTRACTORS

A study program was conducted to define scale-model flowpaths of exhaust systems applicable to supersonic cruise aircraft. Two baseline nozzles were selected for the study; one is representative of single-stream, annular nozzles for application to low bypass ratio turbojets, and the other is an inverted-flow, coannular nozzle for application to variable-cycle engines. Weight studies as a function of the key geometric variables of the baseline nozzles were then conducted. The objective of the weight study was to obtain trends that can be utilized to evaluate trades in weight versus aerodynamic performance. A matrix of scale-model nozzle configurations and wind tunnel conditions was defined using a response surface experiment technique. The resulting matrix will provide a consistent, systematic set of aerodynamic-performance data that can be used to define the impact of nozzle geometric changes on aerodynamic performance. Analytical studies using potential-flow computations methods were conducted on several of the scale-model flowpaths. A gross thrust coefficient, assuming an isolated cylindrical forebody, of 0.976 was calculated for a typical supersonic cruise configuration.

512. SEINER, J. M.; NORUM, T. D.; MAESTRELLO, L.: **Effects of nozzle design on the noise from supersonic jets.** In its Supersonic Cruise Res. 1979, Pt 1, p 479-491 (See 81N17981 09-01) 1980. 81N18001

The aeroacoustic supersonic performance of various internal nozzle geometries is evaluated for shock noise content over a wide range of nozzle pressure ratios. The noise emission of a Mach 1.5 and 2.0 convergent-divergent (C-D) nozzle is measured and compared to convergent nozzles. Comparisons are also made for a Mach 1.5 conical C-D nozzle and a porous plug nozzle. The Mach 1.5 conical C-D nozzle shows a small reduction in shock noise relative to the shock free case of the Mach 1.5 C-D nozzle. The Mach 1.5 C-D nozzle is found to have a wide operating nozzle pressure ratio range around its design point where shock noise remains unimportant compared to the jet mixing noise component. However it is found that the Mach 2 C-D nozzle shows no significant acoustic benefit relative to the convergent nozzle. Results from the porous plug nozzle indicate that shock noise may be completely eliminated, and the jet mixing noise reduced.

513. ANDERSON, B. H.; BEHEIM, M. A.; CLARK, J. S.; CORSON, B. W., JR.; STITT, L. E.; WILCOX, F. A.: **Supersonic exhaust nozzles.** In its Aircraft Propulsion 1971, p 233-282 (See 71N19451) 1971. 71N19459

4.2 AXISYMMETRIC NOZZLES

514. EN, JUN; ZHAO, JINGYUN: **Optimum design for geometric parameters of axisymmetric converging-diverging nozzle.** Journal of Aerospace Power (ISSN 1000-8055), vol. 4, July 1989, p. 271, 272, 294. In Chinese, with abstract in English. 89A52319

A mathematical model of an axisymmetric converging-diverging nozzle in design conditions is set up by quadratic-regression equation. The thrust force coefficient is taken as an objective function. The three geometric parameters (half-convergent angle, half-divergent angle, radius ratio of throat curvature to throat) are chosen as design variables. The optimum design is completed by the random-walk method. The relationships of the optimum geometric parameters to the designed pressure ratio of the nozzle are obtained. The results provide the basis for designing the axisymmetric convergent-divergent nozzle of an exhaust system.

515. MURTHY, S. N. B.; SHEU, W. H.: **Analysis of supersonic plug nozzle flowfield and heat transfer.** NASA-CR-179554 NAS 1.26:179554 1988. 89N13397

A number of problems pertaining to the flowfield in a plug nozzle, designed as a supersonic thruster nozzle, with provision for cooling the plug with a coolant stream admitted parallel to the plug wall surface, were studied.

First, an analysis was performed of the inviscid, nonturbulent, gas dynamic interaction between the primary hot stream and the secondary coolant stream. A numerical prediction code for establishing the resulting flowfield with a dividing surface between the two streams, for various combinations of stagnation and static properties of the two streams, was utilized for illustrating the nature of interactions. Secondly, skin friction coefficient, heat transfer coefficient and heat flux to the plug wall were analyzed under smooth flow conditions (without shocks or separation) for various coolant flow conditions. A numerical code was suitably modified and utilized for the determination of heat transfer parameters in a number of cases for which data are available. Thirdly, an analysis was initiated for modeling turbulence processes in transonic shock-boundary layer interaction without the appearance of flow separation.

516. CONLEY, R. R.; HOFFMAN, J. D.; THOMPSON, H. D.: **An analytical and experimental investigation of annular propulsive nozzles** (American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984, AIAA Paper 84-0282) Journal of Aircraft (ISSN 0021-8669), vol. 22, April 1985, p. 270-276. Previously cited in issue 06, p. 707, Accession no. 84A17996. 1985. 85A29253

517. YAMAMOTO, K.; BRAUSCH, J. F.; BALSA, T. F.; JANARDAN, B. A.; KNOTT, P. R.: **Experimental investigation of shock-cell noise reduction for single stream nozzles in simulated flight**. NASA-CR-3845 E-2282 NAS 1.26:3845 R82AEB492 1984. 85N13550

Seven single stream model nozzles were tested in the Anechoic Free-Jet Acoustic Test Facility to evaluate the effectiveness of convergent divergent (C-D) flow paths in the reduction of shock-cell noise under both static and emulated flight conditions. The test nozzles included a baseline convergent circular nozzle, a C-D circular nozzle, a convergent annular plug nozzle, a C-D annular plug nozzle, a convergent multi-element suppressor plug nozzle, and a C-D multi-element suppressor plug nozzle. Diagnostic flow visualization with a shadowgraph and aerodynamic plume measurements with a laser velocimeter were performed with the test nozzles. A theory of shock-cell noise for annular plug nozzles with shock-cells in the vicinity of the plug was developed. The benefit of these C-D nozzles was observed over a broad range of pressure ratios in the vicinity of their design conditions. At the C-D design condition, the C-D annual nozzle was found to be free of shock-cells on the plug.

518. GRIEB, H.; VEDOVA, R.; ENDERLE, H.; NAGEL, H.: **Comparison of different nozzle concepts for a reheated turbofan**. 1981. 82N13077

Several concepts of convergent and convergent/divergent nozzles are investigated and compared in view of performance, weight, complexity and the influence on afterbody drag of combat aircraft. The influence of different nozzle cooling concepts on thrust, with subsequent cooling air requirements, is investigated. The optimum ratio of exit area/throat area of convergent/divergent nozzles dependent on nozzle concept and nozzle pressure ratio is identified. The performance comparison shows that fully variable convergent/divergent nozzles promise some advantages against the simple convergent nozzle at high nozzle pressure ratios. However, the higher weight and complexity of convergent/divergent nozzles lead to the conclusion that the choice of convergent/divergent nozzles for reheated turbofan engines in combat aircraft is not generally justified.

519. CARSON, G. T., JR.; LEE, E. E., JR.: **Experimental and analytical investigation of axisymmetric supersonic cruise nozzle geometry at Mach numbers from 0.60 to 1.30.** NASA-TP-1953 L-14661 1981. 82N14052

Quantitative pressure and force data for five axisymmetric boattail nozzle configurations were examined. These configurations simulate the variable-geometry feature of a single nozzle design operating over a range of engine operating conditions. Five nozzles were tested in the Langley 16-Foot Transonic Tunnel at Mach numbers from 0.60 to 1.30. The experimental data were also compared with theoretical predictions.

520. KOZLIN, J. R.: **F100 exhaust nozzle area control.** In NASA Langley Research Center Proc. of the 14th Aerospace Mech. Symp., p 211-223 (See 80N23495 14-31) 1980. 80N23513

The details of the F100 nozzle mechanism design are highlighted, placing particular emphasis upon the evolution of design constraints or drivers from initial concept through current operational deployment. A kinematic description of the area control mechanism is given, and several environmental constraints which complicate the normal mechanism design process are discussed.

521. SORENSEN, N. E.; LATHAM, E. A.: **Aircraft engine nozzle.** NASA-CASE-ARC-10977-1 US-PATENT-4,214,703. US-PATENT-APPL-SN-023436. US-PATENT-CLASS-239-127.3 US-PATENT-CLASS-60-264 US-PATENT-CLASS-239-265.33 1980. 80N32392

A variable area exit nozzle arrangement for an aircraft engine was a substantially reduced length and weight which comprises a number of longitudinally movable radial vanes and a number of fixed radial vanes. The movable radial vanes are alternately disposed with respect to the fixed radial vanes. A means is provided for displacing the movable vanes along the longitudinal axis of the engine relative to the fixed radial vanes which extend across the main exhaust flow of the engine.

522. SEINER, J. M.; NORUM, T. D.; MAESTRELLO, L.: **Effects of nozzle design on the noise from supersonic jets.** In its Supersonic Cruise Res. 1979, Pt. 1, p 479-491 (See 81N17981 09-01) 1980. 81N18001

The aeroacoustic supersonic performance of various internal nozzle geometries is evaluated for shock noise content over a wide range of nozzle pressure ratios. The noise emission of a Mach 1.5 and 2.0 convergent-divergent (C-D) nozzle is measured and compared to convergent nozzles. Comparisons are also made for a Mach 1.5 conical C-D nozzle and a porous plug nozzle. The Mach 1.5 conical C-D nozzle shows a small reduction in shock noise relative to the shock free case of the Mach 1.5 C-D nozzle. The Mach 1.5 C-D nozzle is found to have a wide operating nozzle pressure ratio range around its design point where shock noise remains unimportant compared to the jet mixing noise component. However it is found that the Mach 2 C-D nozzle shows no significant acoustic benefit relative to the convergent nozzle. Results from the porous plug nozzle indicate that shock noise may be completely eliminated, and the jet mixing noise reduced.

523. LAZKOV, V. M.; DUGANOV, V. V.; POLIAKOV, V. V.; PUZYREV,V. M.: **Experimental study of plane asymmetric nozzle models in overexpansion regimes.** (Aviatsionnaia Tekhnika, vol. 22, no. 3, 1979, p. 23-27.) Soviet Aeronautics, vol. 22, no. 3, 1979, p. 17-20. Translation. 80A47416

Experimental results are presented on flow in an asymmetric plane nozzle in the overexpansion regime for a nozzle inlet Mach number of 2. The wall pressure distribution was determined and the nozzle thrust characteristics were studied by the force balance technique. A finite difference scheme was used to analyze flow in nozzles with sideplates in the overexpansion regime.

4.3 2-DIMENSIONAL NOZZLES

524. CHOI, Y. H., SOH, W. Y.; **Computational analysis of a two-dimensional ejector nozzle.**: AIAA PAPER 90-1901 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 26th, Orlando, Fl, July 16-18, 1990, 16 p. 90N-23406.

A time-iterative full Navier-Stokes code, PARC, is used to analyze the flowfield of a two-dimensional ejector nozzle.

525. FLUGSTAD, T. H.; ROMINE, B. M.; WHITTAKER, R. W.: **High Mach exhaust system concept scale model test results.** AIAA PAPER 90-1905 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 26th, Orlando, FL, July 16-18, 1990. 8 p. 90A40552

The results of a scale model test of the Two-Dimensional Convergent-Divergent (2DCD) and Two-Dimensional Single Expansion Ramp Nozzle (SERN) configurations are presented to assess the performance, to establish geometric design criteria, and to validate advanced computational fluid dynamics codes for Mach 4 to 6 applications. The major conclusions derived are that the peak performance for all systems is comparable to the existing lower Mach nozzle designs; the ejector pumping performance is, in general, comparable to the existing ejector nozzle performance; and the predicted performance was consistently below levels of the performance measured in the scale model test. The nozzles tested are considered viable candidates for high Mach applications, and the test data provide an extensive design data base.

526. TAYLOR, JOHN G.: **Static investigation of a two-dimensional convergent-divergent exhaust nozzle with multiaxis thrust-vectoring capability.** NASA-TP-2973 L-16632 NAS 1.60:2973 1990. 90N19193

An investigation was conducted in the Static Test Facility of the NASA Langley 16-Foot Transonic Tunnel to determine the internal performance of two-dimensional convergent-divergent nozzles designed to have simultaneous pitch and yaw thrust vectoring capability.

This concept utilized divergent flap rotation of thrust vectoring in the pitch plane and deflection of flat yaw flaps hinged at the end of the sidewalls for yaw thrust vectoring. The hinge location of the yaw flaps was varied at four positions from the nozzle exit plane to the throat plane. The yaw flaps were designed to contain the flow laterally independent of power setting. In order to eliminate any physical interference between the yaw flap deflected into the exhaust stream and the divergent flaps, the downstream corners of both upper and lower divergent flaps were cut off to allow for up to 30 deg of yaw flap deflection. The impact of varying the nozzle pitch vector angle, throat area, yaw flap hinge location, yaw flap length, and yaw flap deflection angle on nozzle internal performance characteristics, was studied. High-pressure air was used to simulate jet exhaust at nozzle pressure ratios up to 7.0. Static results indicate that configurations with the yaw flap hinge located upstream of the exit plane provide relatively high levels of thrust vectoring efficiency without causing large losses in resultant thrust ratio. Therefore, these configurations represent a viable concept for providing simultaneous pitch and yaw thrust vectoring.

527. ARGROW, BRIAN M.; EMANUEL, GEORGE: **A computational analysis of the transonic flow field of two-dimensional minimum length nozzles.** AIAA PAPER 89-1822 AIAA, Fluid Dynamics, Plasma Dynamics and Lasers Conference, 20th, Buffalo, NY, June 12-14, 1989. 22 p. 89A42052

The method of characteristics is used to generate supersonic wall contours for two-dimensional, straight sonic line (SSL) and curved sonic line (CSL)minimum length nozzles for exit Mach numbers of two, four and six. These contours are combined with subsonic inlets to determine the influence of the inlet geometry on the sonic-line shape and location and on the supersonic flow field. A modified version of the code VNAP2 is used to compute the inviscid and laminar flow fields for Reynolds numbers of 1,170, 11,700, and 23,400. Results indicate that the inlet geometry directly determines the sonic-line shape and location. Supersonic flow field phenomena, including boundary-layer separation and oblique shock waves, are observed to be a direct result of the inlet geometry. The sonic-line assumptions made for the SSL prove to be superior to those of the CSL.

528. MASON, MARY L.; BERRIER, BOBBY L.: **Static performance of non axisymmetric nozzles with yaw thrust-vectoring vanes.** NASA-TP-2813 L-16389 NAS 1.60:2813 1988. 88N21118

A static test was conducted in the static test facility of the Langley 16 ft Transonic Tunnel to evaluate the effects of post exit vane vectoring on non axisymmetric nozzles. Three baseline nozzles were tested: an unvectored two dimensional convergent nozzle, an unvectored two dimensional convergent-divergent nozzle, and a pitch vectored two dimensional convergent-divergent nozzle. Each nozzle geometry was tested with 3 exit aspect ratios (exit width divided by exit height) of 1.5, 2.5 and 4.0. Two post exit yaw vanes were externally mounted on the nozzle sidewalls at the nozzle exit to generate yaw thrust vectoring. Vane deflection angle (0, -20 and -30 deg), vane planform and vane curvature were varied during the test. Results indicate that the post exit vane concept produced resultant yaw vector angles which were always smaller than the geometric yaw vector angle. Losses in resultant thrust ratio increased with the magnitude of resultant yaw vector angle. The widest post exit vane produced the largest degree of flow turning, but vane curvature had little effect on thrust vectoring. Pitch vectoring was independent of yaw vectoring, indicating that multiaxis thrust vectoring is feasible for the nozzle concepts tested.

529. CAPONE, FRANCIS J.; BARE, E. ANN: **Multiaxis control power from thrust vectoring for a supersonic fighter aircraft model at Mach 0.20 to 2.47.** NASA-TP-2712 L-16213 NAS 1.60:2712 1987. 87N24433

The aeropropulsive characteristics of an advanced twin-engine fighter aircraft designed for supersonic cruise have been studied in the Langley 16-Foot Transonic Tunnel and the Lewis 10- by 10-Foot Supersonic Tunnel. The objective was to determine multiaxis control-power characteristics from thrust vectoring. A two-dimensional convergent-divergent nozzle was designed to provide yaw vector angles of 0, -10, and -20 deg combined with geometric pitch vector angles of 0 and 15 deg. Yaw thrust vectoring was provided by yaw flaps located in the nozzle sidewalls. Roll control was obtained from differential pitch vectoring. This investigation was conducted at Mach numbers from 0.20 to 2.47. Angle of attack was varied from 0 to about 19 deg, and nozzle pressure ratio was varied from about 1 (jet off) to 28, depending on Mach number. Increments in force or moment coefficient that result from pitch or yaw thrust vectoring remain essentially constant over the entire angle-of-attack range of all Mach numbers tested. There was no effect of pitch vectoring on the lateral aerodynamic forces and moments and only very small effects of yaw vectoring on the longitudinal aerodynamic forces and moments. This result indicates little cross-coupling of control forces and moments for combined pitch-yaw vectoring.

530. ILMOTH, RICHARD G.; LEAVITT, LAURENCE D.: **Navier-Stokes predictions of multifunction nozzle flows.** SAE PAPER 871753 SAE, Aerospace Technology Conference and Exposition, Long Beach, CA, Oct. 5-8, 1987. 17 p. 88A30766

A two-dimensional, Navier-Stokes code developed by Imlay based on the implicit, finite-volume method of MacCormack has been applied to the prediction of the flow fields and performance of several nonaxisymmetric, convergent-divergent nozzles with and without thrust vectoring. Comparisons of predictions with experiment show that the Navier-Stokes code can accurately predict both the flow fields and performance for nonaxisymmetric nozzles where the flow is predominantly two-dimensional and at nozzle pressure ratios at or above the design values. Discrepancies between predictions and experiment are noted at lower nozzle pressure ratios where separation typically occurs in portions of the nozzle. The overall trends versus parameters such as nozzle pressure ratio, flap angle, and vector angle were generally predicted correctly.

531. BROOKE, D.; DUSA, D. J.; KUCHAR, A. P.; ROMINE, B. M. **Initial performance evaluation of 2DCD ejector exhaust systems.** AIAA PAPER 86-1615 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd, Huntsville, AL, June 16-18, 1986. 11 p. 86A42753

An ejector nozzle system can furnish the cooling flow requirement of advanced nonaxisymmetric exhaust nozzles, perhaps yielding improvements in overall propulsion system performance. An equivalent area method is presently developed on the basis of an existing axisymmetric ejector nozzle prediction program for both nozzle performance (thrust coefficient) and the air-handling characteristics of the nonaxisymmetric designs considered. A scale test model program has been conducted to determine static performance and air handling for four different two-dimensional convergent/divergent exhaust systems. Results adequate for preliminary design studies are obtained.

532. CAPONE, F. J.; MASON, M. L.: **Multiaxis aircraft control power from thrust vectoring at high angles of attack.** NASA-TM-87741NAS 1.15:87741 AIAA-86-1779 1986. 86N28054

Extensive research programs conducted at the Langley Research Center have shown that thrust vectoring can be provided by multifunction (nonaxisymmetric) nozzles. Most of this research has been conducted on pitch vectoring at both static and forward flight conditions. Recent efforts have been aimed at evaluating yaw vectoring concepts at static (wind off) conditions. This paper summarizes results for three different twin-engine fighter configurations tested over a Mach number range of 0.15 to 2.47 at angles of attack up to 35 deg. The objective of these investigations was to determine the multiaxis control power characteristics provided by thrust vectoring. All three configurations employed two-dimensional convergent-divergent nozzles which provided pitch vectoring by differential deflection of the upper and lower nozzle divergent flaps. Three different means of yaw vectoring were tested: (1) a translating nozzle sidewall; (2) yaw flaps located in the nozzle sidewalls; and (3) canted nozzles. These investigations were conducted in the Langley 16-Foot Transonic Tunnel and the Lewis 10x10-Foot Supersonic Tunnel. Longitudinal and direction control power from thrust vectoring was greater than that provided by aerodynamic control effectors at low speed or at high angles of attack.

533. GAL-OR, B.; RASPUTNIS, A.: **2-D, vectoring/reversing nozzles for new fighter engines - A review** IN: Israel Annual Conference on Aviation and Astronautics, 28th, Tel Aviv and Haifa, Israel, Feb. 19, 20, 1986, Collection of Papers (87A35001 14-01). Haifa, Technion Israel Institute of Technology, 1986, p. 225-234. 87A35026

The U.S. Advanced Tactical Fighter is designed to be operative in the mid 90's. It is to be equipped with two-dimensional vectoring/reversing exhaust nozzles. In 1988 the first two-dimensional nozzles will be flight-tested on an F-15 demonstrator fighter. Various laboratory tests have been conducted in recent years to assess the performance of such engine nozzles, especially with respect to STOL and 'Viffing' performance.The new characteristics of such fighters will dramatically change fighter combat. Some of these new engine nozzle characteristics are reviewed, while the performances of various jet-engines are compared.

534. GAL-OR, B.; RASPUTNIS, A.; CHERULNIC, G. L.; VARSHAY, H.: **Film cooling requirements in 2-D converging/diverging vectoring/reversing nozzles** IN: Israel Annual Conference on Aviation and Astronautics, 28th, Tel Aviv and Haifa, Israel, Feb. 19, 20, 1986, Collection of Papers (87A35001 14-01). Haifa, Technion Israel Institute of Technology, 1986, p. 181-185. 87A35021

The development of two-dimensional converging/diverging, vectoring/reversing exhaust nozzles

is examined. The cooling requirements of the converging/diverging flaps and sidewalls of the nozzle are investigated using two-dimensional model simulations. The model represents a gas turbine engine with an air bleeding from a two-stage centrifugal compressor regulated at 1 kg/sec air flow rate and a nominal nozzle throat area of 19 sq cm. It is observed that at subsonic flow the temperature distribution is two-dimensional and the thrust vectoring generates temperature differences between lower and upper divergent flaps; for supersonic operating conditions the temperature distribution is three-dimensional and the thrust vectoring causes lower temperatures on the convex flow path of the divergent flap.

535. CAPONE, FRANCIS J.; MASON, MARY L.: **Multiaxis aircraft control power from thrust vectoring at high angles of attack.** AIAA PAPER 86-1779 AIAA, Applied Aerodynamics Conference, 4th, San Diego, CA,June 9-11, 1986. 50 p. Previously announced in STAR as 86N28054. 1986. 87A40272

Extensive research programs conducted at the Langley Research Center have shown that thrust vectoring can be provided by multifunction (nonaxisymmetric) nozzles. Most of this research has been conducted on pitch vectoring at both static and forward flight conditions. Recent efforts have been aimed at evaluating yaw vectoring concepts at static (wind off) conditions. This paper summarizes results for three different twin-engine fighter configurations tested over a Mach number range of 0.15 to 2.47 at angles of attack up to 35 deg. The objective of these investigations was to determine the multiaxis control power characteristics provided by thrust vectoring. All three configurations employed two-dimensional convergent-divergent nozzles which provided pitch vectoring by differential deflection of the upper and lower nozzle divergent flaps. Three different means of yaw vectoring were tested: (1) a translating nozzle sidewall; (2) yaw flaps located in the nozzle sidewalls; and (3) canted nozzles. These investigations were conducted in the Langley 16-Foot Transonic Tunnel and the Lewis 10 x 10-Foot Supersonic Tunnel. Longitudinal and direction control power from thrust vectoring was greater than that provided by aerodynamic control effectors at low speed or at high angles of attack.

536. ROWE, R. K.; DUSS, D. J.; LEAVITT, L. D.: **Static internal performance evaluation of several thrust reversing concepts for 2D-CD nozzles.** AIAA PAPER 84-1174 AIAA, SAE, and ASME, Joint Propulsion Conference, 20th, Cincinnati, OH, June 11-13, 1984. 7 p. 84A37628

Recent performance testing of the two-dimensional convergent-divergent (2D-CD) nozzle has established the concept as a viable alternative to the axisymmetric nozzle for advanced technology aircraft. This type of exhaust system also offers potential integration and performance advantages in the areas of thrust reversing and vectoring over axi-symmetric nozzles. These advantages include the practical integration of thrust reversers which operate not only to reduce landing roll but also operate in-flight for enhanced maneuvering and thrust spoiling. To date there is a very limited data base available from which criteria can be developed for the design and evaluation of this type of thrust reverser system. For this reason, a static scale model test was conducted in which five different thrust reverser designs were evaluated. Each of the five models had varying performance/integration requirements which dictated the five different designs. Some of the parameters investigated in this test included; variable angle external cascade vanes, fixed angle internal cascade vanes,variable position inner doors, external slider doors and internal slider valves. In addition, normal force and yawing moment generation was investigated using the thrust reverser system. Selected results from this test will be presented and discussed in this paper.

537. BERRIER, B. L.; MASON, M. L.: **A static investigation of yaw vectoring concepts on two-dimensional convergent-divergent nozzles.** AIAA PAPER 83-1288 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 13 p. 83A36324

The flow-turning capability and nozzle internal performance of yaw-vectoring nozzle geometries were tested in the NASA Langley 16-ft Transonic wind tunnel. The concept was investigated as a means of enhancing fighter jet performance. Five two-dimensional convergent-divergent nozzles were equipped for yaw-vectoring and examined.The configurations included a translating left sidewall, left and right sidewall flaps downstream of the nozzle throat, left sidewall flaps or port located upstream of the nozzle throat, and a powered rudder. Trials were also run with 20 deg of pitch thrust vectoring added. The feasibility of providing yaw-thrust vectoring was demonstrated, with the largest yaw vector angles being obtained with sidewall flaps downstream of the nozzle primary throat. It was concluded that yaw vector designs that scoop or capture internal nozzle flow provide the largest yaw-vector capability, but decrease the thrust the most.

538. CAPONE, F. J.; HUNT, B. L.; POTH, G. E.: **Subsonic/supersonic aeropropulsive characteristics of nonaxisymmetric nozzles installed on an F-18 model.** (AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA Paper 81-1445) Journal of Aircraft (ISSN 0021-8669), vol. 20, Oct. 1983, p. 853-858. 83A48215

Previously cited in issue 19, p. 3266, Accession no. 81A40878

539. New nozzle design aimed at F-15, F-16 aircraft. Aviation Week and Space Technology, vol. 117, Sept. 13, 1982, p. 67, 71, 73. 1982. 82A43092

The two-dimensional convergent/divergent nozzle consists of two convergent/divergent flaps which vary thrust and exit area as well as control vectoring and reversing. Vectoring on the order of + or - 30 degrees is possible. Designed for short takeoff and landing, and for high Mach maneuvering, landing distances on dry runways are reduced from 3,000 to 1,000 feet, and from 10,000 to 1,200 feet on icy runways. The rectangular nozzle has lower cost and weight than circular nozzles with the same capacity. Ground demonstration tests produced a maximum 8,000 pound perpendicular thrust component and 6,200 pounds of reverse thrust. The nozzle could be employed in an F-15 or F-16, and several external contours for it are being considered.

540. WARBURTON, R. E.: **Advanced exhaust nozzle system demonstration. Part 1. The 2-D nozzle technology.** AD-B068631L FR-15378 AFWAL-TR-82-2051- PT-1 1982. 83X71560 US GOV AGENCIES

541. STEVENS, H. L.; THAYER, E. B.; FULLERTON, J. F.: **Development of the multi-function 2-C-D nozzle.** AIAA PAPER 81-1491 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 12 p. 81A42203

An account is given of the development to date of the multi-function, two-dimensional/convergent-divergent (2-C-D) nozzle concept. Conceived to meet projected performance requirements of next-generation fighter aircraft, the mechanical configuration of the nozzle allows both conventional jet area and expansion area variations and the more advanced vectoring and reversal of thrust. Among the topics covered are: mechanical actuation system details, throat locations and geometries in axial and vectored modes, external, sidewall and internal flow geometries and their effect on performance, pressure ratio comparisons with an axisymmetric nozzle of comparable output and sophistication, and hot flow circular-to-rectangular cross section discontinuity effects.

542. CAPONE, F. J.; HUNT, B. L.; POTH, G. E.: **Subsonic/supersonic nonvectored aeropropulsive characteristics of nonaxisymmetric nozzles installed on an F-18 model.** AIAA PAPER 81-1445 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 12 p. 81A40878

An experimental program on a model of the F-18 airplane has been conducted to determine the performance of nonaxisymmetric nozzles relative to the aircraft's baseline axisymmetric nozzle at Mach numbers from 0.60 to 2.20. The performance of a two-dimensional convergent-divergent nozzle, a single expansion ramp nozzle (ADEN) and a wedge nozzle were compared to the baseline axisymmetric nozzles. The nonaxisymmetric nozzles (except ADEN) were designed for vectoring and reversing. The axisymmetric nozzle did not have these capabilities. The comparisons presented here are for the nozzles in their full forward thrust mode and for the aircraft at zero angle of attack. The results demonstrate that nonaxisymmetric nozzles can be installed on a close-spaced twin engine fighter with equal or higher performance than the axisymmetric nozzle over the range of Mach numbers tested.

543. MASON, M. L.; PUTNAM, L. E.; RE, R. J.: **The effect of throat contouring on two-dimensional converging-diverging nozzles at static conditions.** NASA-TP-1704 L-13591 1980. 80N29250

An experiment was conducted at static conditions to determine the internal performance effects of nozzle throat contouring, the result of increasing the circular-arc throat radius. Five nonaxisymmetric converging-diverging nozzles were tested at nozzle pressure ratios up to 9.0. Data are presented as internal thrust ratios, discharge coefficients, and static-pressure distributions. Comparisons of internal performance data for the five nozzles show that throat contouring increases the value of discharge coefficient but has no significant effect on internal thrust ratio except in cases of internal flow separation. To illustrate the use of the two dimensional converging-diverging (2-D C-D) nozzle data base, a two dimensional inviscid theory was applied to the five configurations. The generally good agreement of data with theoretical results indicates that two-dimensional inviscid

theory can be successfully applied to the prediction of 2-D C-D nozzle internal flow.

544. SUSSMAN, M. B.: **Feasibility study of an F-106 aircraft for nonaxisymmetric nozzle flight research.** NASA-CR-162657 D180-25418-11979. 80N71545

545. PETIT, J. E.: **Investigation of a non-axisymmetric nozzle using an F-18 jet effects wind tunnel model. Volume 1: Wind tunnel test results.** AD-B0423281L D180-25476-1 1979. 80X74201 US GOV AGENCIES

546. GOWADIA, N. S.: **Analysis of nonaxisymmetric nozzles installed on a high performance tactical fighter.** AD-B043993L NOR-79-81 1979. 80X73813 US GOV AGENCIES

547. BERGMAN, D.; SAVAGE, T. M.; THAYER, E. B.: **AFTI-111 2-d nozzle preliminary systems study. Volume 3, Phase 3: F-111.** AD- B039575 AFFDL-TR-79-3004-VOL-3 1979. 80X71329 US GOV AGENCIES

548. BERGMAN, D.; SAVAGE, T. M.; THAYER, E. B.: **AFTI-111 2-d nozzle preliminary systems study. Volume 2, Phase 2: Refined nozzle/airframe design and performance.** AD-B039574 AFFDL-TR-79-3004-VOL-2 1979. 80X71328 US GOV AGENCIES

549. BERGMAN, D.; SAVAGE, T. M.; THAYER, E. B.: **AFTI-111 2-d nozzle preliminary systems study. Volume 1, Phase 1: Preliminary nozzle/airframe trade studies.** AD-B039573 AFFDL-TR-79-3004-VOL-1 1979. 80X71327 US GOV AGENCIES

4.4 COAXIAL NOZZLES

550. Low speed test of a naturally aspirated co-annular nozzle, volume 1. NASA-CR-168043 NAS 1.26:168043 1983. 83X10189 US GOV AGENCIES AND CONTRACTORS

A model of a naturally aspirated co-annular (NACA) exhaust nozzle, designed for an engine with a high-specific-thrust supersonic-cruise application, was tested at low speed to determine its thrust and secondary flow characteristics. The NACA nozzle performance and flow-pumping tests covered a range of secondary-to-primary nozzle throat area ratios and two primary-jet-axis inclinations. The tests were conducted both statically and at Mach 0.28 in the Boeing 2.74m by 2.74m (9 by 9ft) low-speed wind tunnel. The primary stream nozzle pressure ratio was varied from 2.0 to 4.5 to cover the applicable range of engine operating conditions during takeoff and noise-abatement (power-cutback) procedures. A reference high-radius-ratio plug nozzle, designed for the same engine application but not incorporating the ambient flow aspirating feature, was also tested in order to provide a measure of the effects of the aspirating feature on performance. A reference round-convergent nozzle was also tested to establish a base level for noise prediction analysis and to permit verification of the performance levels and tare drags of the test setup.

551. GOODYKOONTZ, J.; VONGLAHN, U.: **Noise suppression due to annulus shaping of an inverted-velocity-profile coaxial nozzle.** NASA-TM-81460 E-389. 1980. 80N22046

An inverted velocity profile coaxial nozzle for use with supersonic cruise aircraft produces less jet noise than an equivalent conical nozzle. Furthermore, decreasing the annulus height (increasing radius ratio with constant flow) results in further noise reduction benefits. The annulus shape (height) was varied by an eccentric mounting of the annular nozzle with respect to a conical core nozzle. Acoustic measurements were made in the flyover plane below the narrowest portion of the annulus and at 90 deg and 180 deg from this point. The model-scale spectra are scaled up to engine size (1.07 m diameter) and the perceived noise levels for the eccentric and baseline concentric inverted velocity profile coaxial nozzles are compared over a range of operating conditions. The implications of the acoustic benefits derived with the eccentric nozzle to practical applications are discussed.

552. DEAN, P. D.; SALIKUDDIN, M.; AHUJA, K. K.; PLUMBLEE, H. E.; MUNGUR, P.: **Studies of the acoustic transmission characteristics of coaxial nozzles with inverted velocity profiles, volume 1.** NASA-CR-159698 LG79ER0178-VOL-1 1979. 80N11870

The efficiency of internal noise radiation through coannular exhaust nozzle with an inverted velocity profile was studied. A preliminary investigation was first undertaken to: (1) define the test parameters which influence the internal noise radiation; (2) develop a test methodology which could realistically be used to examine the effects of the test parameters; (3) and to validate this methodology. The result was the choice of an acoustic

impulse as the internal noise source in the in the jet nozzles. Noise transmission characteristics of a nozzle system were then investigated. In particular, the effects of fan nozzle convergence angle, core extension length to annulus height ratio, and flow Mach number and temperatures were studied. The results are presented as normalized directivity plots.

553. GOODYKOONTZ, J.; VONGLAHN, U.: **Noise suppression due to annulus shaping of an inverted-velocity-profile coaxial nozzle.** NASA-TM-81460 E-389 1980. 80N22046

An inverted velocity profile coaxial nozzle for use with supersonic cruise aircraft produces less jet noise than an equivalent conical nozzle. Furthermore, decreasing the annulus height (increasing radius ratio with constant flow) results in further noise reduction benefits. The annulus shape (height) was varied by an eccentric mounting of the annular nozzle with respect to a conical core nozzle. Acoustic measurements were made in the flyover plane below the narrowest portion of the annulus and at 90 deg and 180 deg from this point. The model-scale spectra are scaled up to engine size (1.07 m diameter) and the perceived noise levels for the eccentric and baseline concentric inverted velocity profile coaxial nozzles are compared over a range of operating conditions. The implications of the acoustic benefits derived with the eccentric nozzle to practical applications are discussed.

554. JANARDAN, B. A.; YAMAMOTO, K.; MAJJIGI, R. K.; BRAUSCH, J. F.: **Experimental investigation of shock-cell noise reduction for dual-stream nozzles in simulated flight.** NASA-CR-3846 E-2283 NAS 1.26:3846 R83AEB358 1984. 85N13549

Six scale-model nozzles were tested in an anechoic facility to evaluate the effectiveness of convergent-divergent (C-D) terminations in reducing shock-cell noise of unsuppressed and mechanically suppressed coannular plug nozzles. One hundred fifty-three acoustic test points with inverted velocity profiles were conducted under static and simulated flight conditions. Diagnostic flow visualization with a shadowgraph and velocity measurements with a laser velocimeter were performed on selected plumes. Shock-cells were identified on the plug and downstream of the plug of the unsuppressed convergent coannular nozzle with truncated plug. Broadband peak frequencies predicted with the two shock-cell structures were correlated with the observed spectra using the measured shock-cell spacings. Relative to a convergent circular nozzle, the perceived noise level (PNL) data at an observer angle of 60 deg relative to inlet, indicated a reduction of (1) 6.5 Db and 9.2 dB with unsuppressed C-D coannular nozzle with truncated plug and (2) 7.7 dB and 8.3 dB with suppressed C-D coannular nozzle under static and simulated flight conditions, respectively. The unsuppressed C-D coannular nozzle with truncated plug, operating at the C-D design condition, had shock-cells downstream of the plug with no shock-cells on the plug. The downstream shock-cells were eliminated by replacing the truncated plug with a smooth extension to obtain an additional 2.4 dB and 3 dB front quadrant PNL reduction, under static and simulated flight conditions, respectively. Other results are discussed.

555. YAMAMOTO, K.; JANARDAN, B. A.; BRAUSCH, J. F.; HOERST, D.J.; PRICE, A. O.: **Experimental investigation of shock-cell noise reduction for dual-stream nozzles in simulated flight comprehensive data report. Volume 1: Test nozzles and acoustic data.** NASA-CR-168336-VOL-1 NAS 1.26:168336-VOL-1 R83AEB358-VOL-1 1984. 84N24323

Parameters which contribute to supersonic jet shock noise were investigated for the purpose of determining means to reduce such noise generation to acceptable levels. Six dual-stream test nozzles with varying flow passage and plug closure designs were evaluated under simulated flight conditions in an anechoic chamber. All nozzles had combined convergent-divergent or convergent flow passages. Acoustic behavior as a function of nozzle flow passage geometry was measured. The acoustic data consist primarily of 1/3 octave band sound pressure levels and overall sound pressure levels. Detailed schematics and geometric characteristics of the six scale model nozzle configurations and acoustic test point definitions are presented. Tabulation of aerodynamic test conditions and a computer listing of the measured acoustic data are displayed.

556. YAMAMOTO, K.; JANARDAN, B. A.; BRAUSCH, J. F.; HOERST, D.J.; PRICE, A. O.: **Experimental investigation of shock-cell noise reduction for dual-stream nozzles in simulated flight comprehensive data report. Volume 2: Laser velocimeter data, static pressures and shadowgraph photos.** NASA-CR-168336-VOL-2 NAS 1.26:168336-VOL-2 R83AEB358-VOL-2 1984. 84N24324

Parameters which contribute to supersonic jet shock noise were investigated for the purpose of determining means to reduce such noise generation to acceptable levels. Six dual-stream test nozzles with varying flow passage and plug closure designs were evaluated under simulated flight

conditions in an anechoic chamber. All nozzles had combined convergent-divergent or convergent flow passages. Mean velocity and turbulence velocity measurements of 25 selected flow conditions were performed employing a laser Doppler velocimeter. Static pressure measurements were made to define the actual convergence-divergence condition. Test point definition, tabulation of aerodynamic test conditions, velocity histograms, and shadowgraph photographs are presented. Flow visualization through shadowgraph photography can contribute to the development of an analytical prediction model for shock noise from coannular plug nozzles.

557. NELSON, D. P.; MORRIS, P. M.: **Experimental aerodynamic and acoustic model testing of the Variable Cycle Engine (VCE) testbed coannular exhaust nozzle system: Comprehensive data report.** NASA-CR-159711 PWA-5550-40 1980. 80N26301

The component detail design drawings of the one sixth scale model of the variable cycle engine testbed demonstrator exhaust system tested are presented. Also provided are the basic acoustic and aerodynamic data acquired during the experimental model tests. The model drawings, an index to the acoustic data, an index to the aerodynamic data, tabulated and graphical acoustic data, and the tabulated aerodynamic data and graphs are discussed.

558. NELSON, D. P.; MORRIS, P. M.: **Experimental aerodynamic and acoustic model testing of the Variable Cycle Engine (VCE) testbed coannular exhaust nozzle system.** NASA-CR-159710 PWA-5550-31 1980. 80N26300

Aerodynamic performance and jet noise characteristics of a one sixth scale model of the variable cycle engine testbed exhaust system were obtained in a series of static tests over a range of simulated engine operating conditions. Model acoustic data were acquired. Data were compared to predictions of coannular model nozzle performance. The model, tested with an without a hardwall ejector, had a total flow area equivalent to a 0.127 meter (5 inch) diameter conical nozzle with a 0.65 fan to primary nozzle area ratio and a 0.82 fan nozzle radius ratio. Fan stream temperatures and velocities were varied from 422 K to 1089 K (760 R to 1960 R) and 434 to 755 meters per second (1423 to 2477 feet per second). Primary stream properties were varied from 589 to 1089 K (1060 R to 1960 R) and 353 to 600 meters per second (1158 to 1968 feet per second). Exhaust plume velocity surveys were conducted at one operating condition with and without the ejector installed. Thirty aerodynamic performance data points were obtained with an unheated air supply. Fan nozzle pressure ratio was varied from 1.8 to 3.2 at a constant primary pressure ratio of 1.6; primary pressure ratio was varied from 1.4 to 2.4 while holding fan pressure ratio constant at 2.4. Operation with the ejector increased nozzle thrust coefficient 0.2 to 0.4 percent.

559. KNOTT, P. R.; BLOZY, J. T.; STAID, P. S.: **Acoustic and aerodynamic performance investigation of inverted velocity profile coannular plug nozzles.** NASA-CR-3149 R79AEG388 1981. 81N16854

The results of model scale parametric static and wind tunnel aerodynamic performance tests on unsuppressed coannular plug nozzle configurations with inverted velocity profile are discussed. The nozzle configurations are high-radius-ratio coannular plug nozzles applicable to dual-stream exhaust systems typical of a variable cycle engine for Advanced Supersonic Transport application. In all, seven acoustic models and eight aerodynamic performance models were tested. The nozzle geometric variables included outer stream radius ratio, inner stream to outer stream ratio, and inner stream plug shape. When compared to a conical nozzle at the same specific thrust, the results of the static acoustic tests with the coannular nozzles showed noise reductions of up to 7 PNdB. Extensive data analysis showed that the overall acoustic results can be well correlated using the mixed stream velocity and the mixed stream density. Results also showed that suppression levels are geometry and flow regulation dependent with the outer stream radius ratio, inner stream-to-outer stream velocity ratio and inner stream velocity ratio and inner stream plug shape, as the primary suppression parameters. In addition, high-radius ratio coannular plug nozzles were found to yield shock associated noise level reductions relative to a conical nozzle. The wind tunnel aerodynamic tests showed that static and simulated flight thrust coefficient at typical takeoff conditions are quite good - up to 0.98 at static conditions and 0.974 at a takeoff Mach number of 0.36. At low inner stream flow conditions significant thrust loss was observed. Using an inner stream conical plug resulted in 1% to 2% higher performance levels than nozzle geometries using a bent inner plug.

560. JANARDAN, B. A.; BRAUSCH, J. F.; MAJJIGI, R. K.: **Freejet feasibility study of a thermal acoustic shield concept for AST/VCE application: Dual stream nozzles.** NASA-CR-3867 E-2392 NAS 1.26:38671985. 87N10752

The influence of selected geometric and aerodynamic flow variables of an unsuppressed coannular plug nozzle and a coannular plug nozzle with a 20-chute outer stream suppressor were experimentally determined. A total of 136 static and simulated flight acoustic test points were conducted with 9 scale model nozzles. Also, aerodynamic measurements of four selected plumes were made with a laser velocimeter. The presence of the 180 deg shield produced different mixing characteristics on the shield side compared to the unshield side because of the reduced mixing with ambient air on the shielded side. This resulted in a stretching of the jet, yielding a higher peak mean velocity up to a length of 10 equivalent diameters from the nozzle exit. The 180 deg shield in community orientation around the suppressed coannular plug nozzle yielded acoustic benefit at all observer angles for a simulated takeoff. While the effect of shield-to-outer stream velocity ratio was small at angles up to 120 deg, beyond this angle significant acoustic benefit was realized with a shield-to-outer stream velocity ratio of 0.64.

561. JANARDAN, B. A.; BRAUSCH, J. F.; PRICE, A. O.: **Free jet feasibility study of a thermal acoustic shield concept for AST/VCE application-dual flow. Comprehensive data report. Volume 1: Test nozzles and acoustic data.** NASA-CR-174817 NAS 1.26:174817 R84AEB5701984. 86N23371

Acoustic and diagnostic data that were obtained to determine the influence of selected geometric and aerodynamic flow variables of coannular nozzles with thermal acoustic shields are summarized in this comprehensive data report. A total of 136 static and simulated flight acoustic test points were conducted with 9 scale-model nozzles The tested nozzles included baseline (unshielded), 180 deg shielded, and 360 deg shielded dual flow coannular plug configurations. The baseline configurations include a high radius ratio unsuppressed coannular plug nozzle and a coanuular plug nozzle and a coannular plug nozzle with a 20-chute outer stream suppressor. The tests were conducted at nozzle temperatures and pressure typical of operating conditions of variable cycle engine.

562. JANARDAN, B. A.; BRAUSCH, J. F.; PRICE, A. O.: **Free-jet feasibility study of a thermal acoustic shield concept for AST/VCE application-dual stream nozzles. Comprehensive data report. Volume 2: Laser velocimeter and suppressor. Base pressure data.** NASA-CR-174818 NAS 1.26:174818 R84AEB570 1984. 86N23372

Acoustic and diagnostic data that were obtained to determine the influence of selected geometric and aerodynamic flow variables of coannular nozzles with thermal acoustic shields are summarized in this comprehensive data report. A total of 136 static and simulated flight acoustic test points were conducted with 9 scale-model nozzles. Aerodynamic laser velocimeter measurements were made for four selected plumes. In addition, static pressure data in the chute base region of the suppressor configurations were obtained to assess the influence of the shield stream on the suppressor base drag.

563. KNOTT, P. R.; JANARDAN, B. A.; MAJJIGI, R. K.; BHUTIANI, P. K.; VOGT, P. G.: **Free-jet acoustic investigation of high-radius-ratio coannular plug nozzles.** NASA-CR-3818 E-2177 NAS 1.26:3818 R83AEB574 1984. 87N10753

The experimental and analytical results of a scale model simulated flight acoustic exploratory investigation of high radius ratio coannular plug nozzles with inverted velocity and temperature profiles are summarized. Six coannular plug nozzle configurations and a baseline convergent conical nozzle were tested for simulated flight acoustic evaluation. The nozzles were tested over a range of test conditions that are typical of a Variable Cycle Engine for application to advanced high speed aircraft. It was found that in simulate flight, the high radius ratio coannular plug nozzles maintain their jet noise and shock noise reduction features previously observed in static testing. The presence of nozzle bypass struts will not significantly affect the acoustic noise reduction features of a General Electric type nozzle design. A unique coannular plug nozzle flight acoustic spectral prediction method was identified and found to predict the measured results quite well. Special laser velocimeter and acoustic measurements were performed which have given new insights into the jet and shock noise reduction mechanisms of coannular plug nozzles with regard to identifying further beneficial research efforts.

564. KNOTT, P. R.; BRAUSCH, J. F.; BHUTIANI, P. K.; MAJJIGI, R. K.; DOYLE, V. L.: **VCE early acoustic test results of General Electric's high-radius ratio coannular plug nozzle.** 1980. 81N17999

Results of variable cycle engine (VCE) early acoustic engine and model scale tests are presented. A summary of an extensive series of far field acoustic, advanced acoustic, and exhaust plume velocity measurements with a laser velocimeter of inverted velocity and temperature profile, high radius ratio coannular plug nozzles on a

YJ101 VCE static engine test vehicle are reviewed. Select model scale simulated flight acoustic measurements for an unsuppressed and a mechanical suppressed coannular plug nozzle are also discussed. The engine acoustic nozzle tests verify previous model scale noise reduction measurements. The engine measurements show 4 to 6 PNdB aft quadrant jet noise reduction and up to 7 PNdB forward quadrant shock noise reduction relative to a fully mixed conical nozzle at the same specific thrust and mixed pressure ratio. The influences of outer nozzle radius ratio, inner stream velocity ratio, and area ratio are discussed. Also, laser velocimeter measurements of mean velocity and turbulent velocity of the YJ101 engine are illustrated. Select model scale static and simulated flight acoustic measurements are shown which corroborate that coannular suppression is maintained in forward speed.

565. GOODYKOONTZ, J.; VONGLAHN, U.: **Noise suppression due to annulus shaping of an inverted-velocity-profile coaxial nozzle.** NASA-TM-81460 E-389 1980. 80N22046

An inverted velocity profile coaxial nozzle for use with supersonic cruise aircraft produces less jet noise than an equivalent conical nozzle. Furthermore, decreasing the annulus height (increasing radius ratio with constant flow) results in further noise reduction benefits. The annulus shape (height) was varied by an eccentric mounting of the annular nozzle with respect to a conical core nozzle. Acoustic measurements were made in the flyover plane below the narrowest portion of the annulus and at 90 deg and 180 deg from this point. The model-scale spectra are scaled up to engine size (1.07 m diameter) and the perceived noise levels for the eccentric and baseline concentric inverted velocity profile coaxial nozzles are compared over a range of operating conditions. The implications of the acoustic benefits derived with the eccentric nozzle to practical applications are discussed.

566. KNOTT, P. R.; BRAUSCH, J. F.; BHUTIANI, P. K.; MAJJIGI, R. K.; DOYLE, V. L.: **VCE early acoustic test results of General Electric's high-radius ratio coannular plug nozzle.** 1980. 81N17999

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567. KNOTT, P. R.; JANARDAN, B. A.; MAJJIGI, R. K.; BHUTIANI, P. K.; VOGT, P. G.: **Free-jet acoustic investigation of high-radius-ratio coannular plug nozzles.** NASA-CR-3818 E-2177 NAS 1.26:3818 R83AEB574 1984. 87N10753

The experimental and analytical results of a scale model simulated flight acoustic exploratory investigation of high radius ratio coannular plug nozzles with inverted velocity and temperature profiles are summarized. Six coannular plug nozzle configurations and a baseline convergent conical nozzle were tested for simulated flight acoustic evaluation. The nozzles were tested over a range of test conditions that are typical of a Variable Cycle Engine for application to advanced high speed aircraft. It was found that in simulate flight, the high radius ratio coannular plug nozzles maintain their jet noise and shock noise reduction features previously observed in static testing. The presence of nozzle bypass struts will not significantly affect the acoustic noise reduction features of a General Electric type nozzle design. A unique coannular plug nozzle flight acoustic spectral prediction method was identified and found to predict the measured results quite well. Special laser velocimeter and acoustic measurements were performed which have given new insights into the jet and shock noise reduction mechanisms of coannular plug nozzles with regard to identifying further beneficial research efforts.

568. GOODYKOONTZ, J.; VONGLAHN, U.: **Noise suppression due to annulus shaping of an inverted-velocity-profile coaxial nozzle.** NASA-TM-81460 E-389 1980. 80N22046

An inverted velocity profile coaxial nozzle for use with supersonic cruise aircraft produces less jet noise than an equivalent conical nozzle. Furthermore, decreasing the annulus height (increasing radius ratio with constant flow) results in further noise reduction benefits. The annulus

shape (height) was varied by an eccentric mounting of the annular nozzle with respect to a conical core nozzle. Acoustic measurements were made in the flyover plane below the narrowest portion of the annulus and at 90 deg and 180 deg from this point. The model-scale spectra are scaled up to engine size (1.07 m diameter) and the perceived noise levels for the eccentric and baseline concentric inverted velocity profile coaxial nozzles are compared over a range of operating conditions. The implications of the acoustic benefits derived with the eccentric nozzle to practical applications are discussed.

569. NELSON, D. P.; MORRIS, P. M.: **Experimental aerodynamic and acoustic model testing of the Variable Cycle Engine (VCE) testbed coannular exhaust nozzle system: Comprehensive data report.** NASA-CR-159711 PWA-5550-40 1980. 80N26301

The component detail design drawings of the one sixth scale model of the variable cycle engine testbed demonstrator exhaust system tested are presented. Also provided are the basic acoustic and aerodynamic data acquired during the experimental model tests. The model drawings, an index to the acoustic data, an index to the aerodynamic data, tabulated and graphical acoustic data, and the tabulated aerodynamic data and graphs are discussed.

570. NELSON, D. P.; MORRIS, P. M.: **Experimental aerodynamic and acoustic model testing of the Variable Cycle Engine (VCE) testbed coannular exhaust nozzle system.** NASA-CR-159710 PWA-5550-31 1980. 80N26300

Aerodynamic performance and jet noise characteristics of a one sixth scale model of the variable cycle engine testbed exhaust system were obtained in a series of static tests over a range of simulated engine operating conditions. Model acoustic data were acquired. Data were compared to predictions of coannular model nozzle performance. The model, tested with an without a hardwall ejector, had a total flow area equivalent to a 0.127 meter (5 inch) diameter conical nozzle with a 0.65 fan to primary nozzle area ratio and a 0.82 fan nozzle radius ratio. Fan stream temperatures and velocities were varied from 422 K to 1089 K (760 R to 1960 R) and 434 to 755 meters per second (1423 to 2477 feet per second). Primary stream properties were varied from 589 to 1089 K (1060 R to 1960 R) and 353 to 600 meters per second (1158 to 1968 feet per second). Exhaust plume velocity surveys were conducted at one operating condition with and without the ejector installed. Thirty aerodynamic performance data points were obtained with an unheated air supply. Fan nozzle pressure ratio was varied from 1.8 to 3.2 at a constant primary pressure ratio of 1.6; primary pressure ratio was varied from 1.4 to 2.4 while holding fan pressure ratio constant at 2.4. Operation with the ejector increased nozzle thrust coefficient 0.2 to 0.4 percent.

571. KNOTT, P. R.; BLOZY, J. T.; STAID, P. S.: **Acoustic and aerodynamic performance investigation of inverted velocity profile coannular plug nozzles.** NASA-CR-3149 R79AEG388 1981. 81N16854

The results of model scale parametric static and wind tunnel aerodynamic performance tests on unsuppressed coannular plug nozzle configurations with inverted velocity profile are discussed. The nozzle configurations are high-radius-ratio coannular plug nozzles applicable to dual-stream exhaust systems typical of a variable cycle engine for Advanced Supersonic Transport application. In all, seven acoustic models and eight aerodynamic performance models were tested. The nozzle geometric variables included outer stream radius ratio, inner stream to outer stream ratio, and inner stream plug shape. When compared to a conical nozzle at the same specific thrust, the results of the static acoustic tests with the coannular nozzles showed noise reductions of up to 7 PNdB. Extensive data analysis showed that the overall acoustic results can be well correlated using the mixed stream velocity and the mixed stream density. Results also showed that suppression levels are geometry and flow regulation dependent with the outer stream radius ratio, inner stream-to-outer stream velocity ratio and inner stream velocity ratio and inner stream plug shape, as the primary suppression parameters. In addition, high-radius ratio coannular plug nozzles were found to yield shock associated noise level reductions relative to a conical nozzle. The wind tunnel aerodynamic tests showed that static and simulated flight thrust coefficient at typical takeoff conditions are quite good - up to 0.98 at static conditions and 0.974 at a takeoff Mach number of 0.36. At low inner stream flow conditions significant thrust loss was observed. Using an inner stream conical plug resulted in 1% to 2% higher performance levels than nozzle geometries using a bent inner plug.

572. NELSON, D. P.: **Model aerodynamic test results for two variable cycle engine coannular exhaust systems at simulated takeoff and cruise conditions.** NASA-CR-159818 PWA-5550-37 1980. 81N13057

Wind tunnel tests were conducted to evaluate the aerodynamic performance of a coannular exhaust nozzle for a proposed variable stream control supersonic

propulsion system. Tests were conducted with two simulated configurations differing primarily in the fan duct flow paths: a short flap mechanism for fan stream control with an isentropic contoured flow splitter, and an iris fan nozzle with a conical flow splitter. Both designs feature a translating primary plug and an auxiliary inlet ejector.Tests were conducted at takeoff and simulated cruise conditions. Data were acquired at Mach numbers of 0, 0.36, 0.9, and 2.0 for a wide range of nozzle operating conditions. At simulated supersonic cruise, both configurations demonstrated good performance, comparable to levels assumed in earlier advanced supersonic propulsion studies. However, at subsonic cruise, both configurations exhibited performance that was 6 to 7.5 percent less than the study assumptions. At take off conditions, the iris configuration performance approached the assumed levels, while the short flap design was 4 to 6 percent less.

573. NELSON, D. P.: **Model aerodynamic test results for two variable cycle engine coannular exhaust systems at simulated takeoff and cruise conditions. Comprehensive data report. Volume 1: Design layouts.** NASA-CR-159819-VOL-1 PWA-5550-50-VOL-1 1981. 81N17081

The design layouts and detailed design drawings of coannular exhaust nozzle models for a supersonic propulsion system are presented. The layout drawings show the assembly of the component parts for each configuration. A listing of the component parts is also given.

574. NELSON, D. P.: **Model aerodynamic test results for two variable cycle engine coannular exhaust systems at simulated takeoff and cruise conditions. Comprehensive data report. Volume 2: Tabulated aerodynamic data book 1.** NASA-CR-159819-VOL-2-BK-1 PWA-5550-50-VOL-2-BK-1 1981. 81N17082

Tabulated data from wind tunnel tests conducted to evaluate the aerodynamic performance of an advanced coannular exhaust nozzle for a future supersonic propulsion system are presented. Tests were conducted with two test configurations: (1) a short flap mechanism for fan stream control with an isentropic contoured flow splitter, and (2) an iris fan nozzle with a conical flow splitter. Both designs feature a translating primary plug and an auxiliary inlet ejector. Tests were conducted at takeoff and simulated cruise conditions. Data were acquired at Mach numbers of 0, 0.36, 0.9, and 2.0 for a wide range of nozzle operating conditions. At simulated supersonic cruise, both configurations demonstrated good performance, comparable to levels assumed in earlier advanced supersonic propulsion studies. However, at subsonic cruise, both configurations exhibited performance that was 6 to 7.5 percent less than the study assumptions. At takeoff conditions, the iris configuration performance approached the assumed levels, while the short flap design was 4 to 6 percent less. Data are provided through test run 25.

575. NELSON, D. P.: **Model aerodynamic test results for two variable cycle engine coannular exhaust systems at simulated takeoff and cruise conditions. Comprehensive data report. Volume 2: Tabulated aerodynamic data book 2.** NASA-CR-159819-VOL-2-BK-2 PWA-5550-50-VOL-2-BK-2 1981. 81N17083

Tabulated aerodynamic data from coannular nozzle performance tests are given for test runs 26 through 37. The data include nozzle thrust coefficient parameters, nozzle discharge coefficients, and static pressure tap measurements.

576. NELSON, D. P.: **Model aerodynamic test results for two variable cycle engine coannular exhaust systems at simulated takeoff and cruise conditions. Comprehensive data report. Volume 2: Tabulated aerodynamic data book 3.** NASA-CR-159819-VOL-2-BK-3 PWA-5550-5-VOL-2-BK-3 1981. 81N17084

Tabulated data from wind tunnel tests evaluating the aerodynamic performance of coannular exhaust nozzles are given for test runs 37 through 65.

577. NELSON, D. P.: **Model aerodynamic test results for two variable cycle engine coannular exhaust systems at simulated takeoff and cruise conditions. Comprehensive data report. Volume 3: Graphical data book 1.** NASA-CR-159819-VOL-3-BK-1 PWA-5550-50-VOL-3-BK-1 1981. 81N17085

A graphical presentation of the aerodynamic data acquired during coannular nozzle performance wind tunnel tests is given. The graphical data consist of plots of nozzle gross thrust coefficient, fan nozzle discharge coefficient, and primary nozzle discharge coefficient. Normalized model component static pressure distributions are presented as a function of primary total pressure, fan total pressure, and ambient static pressure for selected operating conditions. In addition, the supersonic cruise configuration data include plots of nozzle efficiency and secondary-to-fan total pressure pumping characteristics. Supersonic and subsonic cruise data are given.

578. NELSON, D. P.: **Model aerodynamic test results for two variable cycle engine coannular exhaust systems at simulated takeoff and cruise conditions. Comprehensive data report. Volume 3: Graphical data book 2.** NASA-CR-159819-VOL-3-BK-2 PWA-5550-50-VOL-3-BK-2 1981. 81N17086

Graphical data from wind tunnel tests of variable cycle engine coannular exhaust nozzles are given. Specifically, aerodynamic data for takeoff conditions are presented.

4.5 DUAL/MULTIPLE NOZZLES

579. WALKER, S. H.: **Twin jet screech suppression concepts tested for 4.7 percent axisymmetric and two-dimensional nozzle configurations.** AIAA PAPER 90-2150 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 26th, Orlando, FL, July 16-18, 1990. 13 p. 90A42046

The sonic fatigue of nozzle flaps on F-15 and B-1 aircraft has demanded an increase in aeroacoustic research. A 4.7 percent scale, cold, static test was conducted at the Wright Research and Development Center (WRDC) to investigate noise suppression concepts on F-15 axisymmetric and two-dimensional nozzle configurations. These concepts included lateral spacing, secondary air jets, and tab suppression. Nozzle orientation parametrics included nozzle canting and pitch deflection. Design guideline charts are presented showing screech amplitude variation for each suppression and orientation concept.

580. BARDINA, J.; LOMBARD, C. K.: **Three dimensional CSCM method for the compressible Navier-Stokes equations with application to a multi-nozzle exhaust flowfield.** AIAA PAPER 85-1193 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 21st, Monterey, CA, July 8-10, 1985. 10 p. 85A41419

The effective design of three-dimensional flow systems such as a clustered multinozzle shrouded exhaust system requires detailed analysis of the internal flowfield. It is pointed out that new numerical techniques on the most modern vector computers are making these analyses practicable. In this paper, the upwind differenced implicit conservative supra characteristics method (CSCM) for three-dimensional viscous flow is presented. The new method is an implicit 'method of planes' symmetric Gauss-Seidel relaxation scheme. The data is conveniently stored on successive planes along the streamwise coordinate, and the system of equations is solved twice in each successive plane of the streamwise coordinate. The developed new three-dimensional compressible Navier-Stokes algorithm combines the best features of the storage and computationally efficient space marching procedures with the generality of time dependent techniques to solve flows with elliptic and streamwise separated flows.

581. SEINER, J. M.; MANNING, J. C.; PONTON, M. K.: **Dynamic pressure loads associated with twin supersonic plume resonance.** AIAA PAPER 86-1539 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd, Huntsville, AL, June 16-18, 1986. 10 p. 86A42701

The phenomenon of twin supersonic plume resonance is defined and studied as it pertains to high level dynamic loads in the inter-nozzle region of aircraft like the F-15 and B1-A. Using a 1/40th scale model twin jet nacelle with powered choked nozzles, it is found that intense internozzle dynamic pressures are associated with the synchrophased coupling of each plume's jet flapping mode. This condition is found most prevalent when each plume's jet flapping mode has constituent elements composed of the B-type helical instability. Suppression of these fatigue bearing loads was accomplished by simple geometric modifications to only one plume's nozzle.These modifications disrupt the natural selection of the B-type mode and thereby decouple the plumes.

582. SEINER, JOHN M.; MANNING, JAMES C.; PONTON, MICHAEL K.: **Dynamic pressure loads associated with twin supersonic plume resonance.** (AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd,Huntsville, AL, June 16-18, 1986, AIAA Paper 86-1539) AIAA Journal (ISSN 0001-1452), vol. 26, Aug. 1988, p. 954-960. Previously cited in issue 20, p. 2920, Accession no. 86A42701. 89A16111

583. HIBSON, D. V.: **Performance characteristics of clustered nozzles.** AD-A111130 AFIT/GAE/A81D-14 1981. 82N24291

This is an experimental evaluation of the thrust performance of 3 sets of clustered, three-dimensional, converging-diverging, cold flow supersonic nozzles. A cluster of 2, 4 and 6 nozzles were designed and fabricated. Each cluster assembly has the same geometry in that their area ratio, expansion ratio, and total throat area is the same. A single nozzle with the same geometry and total throat area was used to evaluate the creditability of the testing procedure and the performance of the 3 sets of clustered nozzles. The thrust performance of each

nozzle cluster was evaluated by comparison of the measured thrust coefficient of the cluster to that of a single nozzle. The nozzle with the highest thrust coefficient was the cluster of 2 nozzles. Its performance was closely followed by the cluster of 4 nozzles. The nozzle with the lowest thrust coefficient was the cluster of 6 nozzles. The results of this study indicate that the clustering of nozzles improves the thrust performance.

584. YAMAMOTO, K.; JANARDAN, B. A.; BRAUSCH, J. F.; HOERST, D.J.; PRICE, A. O.: **Experimental investigation of shock-cell noise reduction for dual-stream nozzles in simulated flight comprehensive data report.** Volume 1: Test nozzles and acoustic data. NASA-CR-168336-VOL-1 NAS 1.26:168336-VOL-1 R83AEB358-VOL-1 1984. 84N24323

Parameters which contribute to supersonic jet shock noise were investigated for the purpose of determining means to reduce such noise generation to acceptable levels. Six dual-stream test nozzles with varying flow passage and plug closure designs were evaluated under simulated flight conditions in an anechoic chamber. All nozzles had combined convergent-divergent or convergent flow passages. Acoustic behavior as a function of nozzle flow passage geometry was measured. The acoustic data consist primarily of 1/3 octave band sound pressure levels and overall sound pressure levels. Detailed schematics and geometric characteristics of the six scale model nozzle configurations and acoustic test point definitions are presented. Tabulation of aerodynamic test conditions and a computer listing of the measured acoustic data are displayed.

585. YAMAMOTO, K.; JANARDAN, B. A.; BRAUSCH, J. F.; HOERST, D.J.; PRICE, A. O.: **Experimental investigation of shock-cell noise reduction for dual-stream nozzles in simulated flight comprehensive data report.** Volume 2: Laser velocimeter data, static pressures and shadowgraph photos. NASA-CR-168336-VOL-2 NAS 1.26:168336-VOL-2 R83AEB358-VOL-2 1984. 84N24324

Parameters which contribute to supersonic jet shock noise were investigated for the purpose of determining means to reduce such noise generation to acceptable levels. Six dual-stream test nozzles with varying flow passage and plug closure designs were evaluated under simulated flight conditions in an anechoic chamber. All nozzles had combined convergent-divergent or convergent flow passages. Mean velocity and turbulence velocity measurements of 25 selected flow conditions were performed employing a laser Doppler velocimeter. Static pressure measurements were made to define the actual convergence-divergence condition. Test point definition, tabulation of aerodynamic test conditions, velocity histograms, and shadowgraph photographs are presented. Flow visualization through shadowgraph photography can contribute to the development of an analytical prediction model for shock noise from coannular plug nozzles.

586. SEINER, J. M.; MANNING, J. C.; PONTON, M. K.: **Dynamic pressure loads associated with twin supersonic plume resonance.** AIAA PAPER 86-1539 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd, Huntsville, AL, June 16-18, 1986. 10 p. 86A42701

The phenomenon of twin supersonic plume resonance is defined and studied as it pertains to high level dynamic loads in the inter-nozzle region of aircraft like the F-15 and B1-A. Using a 1/40th scale model twin jet nacelle with powered choked nozzles, it is found that intense internozzle dynamic pressures are associated with the synchrophased coupling of each plume's jet flapping mode. This condition is found most prevalent when each plume's jet flapping mode has constituent elements composed of the B-type helical instability. Suppression of these fatigue bearing loads was accomplished by simple geometric modifications to only one plume's nozzle. These modifications disrupt the natural selection of the B-type mode and thereby decouple the plumes.

587. NORUM, T. D.; SHEARIN, J. G.: **Dynamic loads on twin jet exhaust nozzles due to shock noise.** Journal of Aircraft (ISSN 0021-8669),vol. 23, Sept. 1986, p. 728, 729. 87A14369

Acoustic near field data were collected with model single and twin jet nozzles to determine if closely spaced nozzles produce higher acoustic loading than do single nozzles. The tests were spurred by structural failure of the B-1 exhaust nozzle external flaps and similar damage on the F-15. The test was performed using two 5/8 in. ID pipes machined and placed side-by-side to mimic B-1 nozzles. A microphone mounted on the internozzle fairing measured acoustic levels near the nozzle exit plane. The nozzles oscillated significantly more than did a single nozzle over a wide range of nozzle pressure ratios. Acoustic levels in the dual jets exceeded single jet noise by as much as 20 dB, making acoustic resonance a definite candidate for structural damage in the twin jet configuration.

588. WLEZIEN, R. W.: **Nozzle geometry effects on supersonic jet interaction.** AIAA PAPER 87-2694 AIAA, Aeroacoustics Conference, 11th, Sunnyvale, CA, Oct. 19-21, 1987. 10 p. 88A16548

The coupled interaction of jets from two nominally identical convergent/divergent nozzles is examined as a function of nozzle spacing. The screech modes of two coupled jets correspond to those observed for single plumes, but the modal amplitudes are strongly dependent on nozzle spacing. For closely-spaced nozzles, coupling occurs at low jet Mach numbers and is suppressed at high Mach numbers. The converse is true for large spacing. The amplitude of the coupled jets is independent of the nozzle design Mach number, unlike the screech amplitudes of isolated plumes, which decrease near the design point. Interference between the plumes and the relative phasing of the acoustic sources are proposed as mechanisms for the geometry dependence of the jet coupling.

589. SEINER, JOHN M.; MANNING, JAMES C.; PONTON, MICHAEL K.: **Dynamic pressure loads associated with twin supersonic plume resonance.** (AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd,Huntsville, AL, June 16-18, 1986, AIAA Paper 86-1539) AIAA Journal (ISSN 0001-1452), vol. 26, Aug. 1988, p. 954-960. Previously cited in issue 20, p. 2920, Accession no. 86A42701. 89A16111

4.6 COANDA NOZZLES

590. VABEVILAQUA, P. M.; LEE, J. D.: **Development of a nozzle to improve the turning of supersonic Coanda jets.** AD-A087709 NR80H-18 AFWAL-TR-80-3027 1980. 80N31765

The hypothesis that shaping the jet velocity profile improved the thrust vectoring of supersonic Coanda jets was experimentally tested. A new nozzle design procedure, based on the method of characteristics, was developed to design a nozzle which delivers an arbitrary exit velocity profile. Such a nozzle was designed for a pressure ratio of 2.5, to provide a jet matched to a circular Coanda surface with radius equal to five jet thicknesses. The thrust vectoring of this nozzle was then compared to that of a convergent divergent nozzle over a range of pressure ratios from 1.5 to 3.5. It is concluded that supersonic nozzles provide greatly improved turning of Coanda jets, and that shaping the velocity profile further improves the thrust vectoring.

591. BEVILAQUA, PAUL M.; LEE, JOHN D.: **Design of supersonic Coanda jet nozzles.** In NASA, Ames Research Center Proceedings of the Circulation-Control Workshop, 1986, p 289-313 (see 88N17586 10-02) 1987. 88N17599

The thrust vectoring of supersonic Coanda jets was improved by designing a nozzle to skew the initial jet velocity profile. A new nozzle design procedure, based on the method of characteristics, was developed to design a nozzle which produces a specified exit velocity profile. The thrust vectoring of a simple convergent nozzle, a convergent-divergent nozzle, and a nozzle which produces a skewed velocity profile matched to the curvature of the Coanda surface were expermentially compared over a range of pressure ratios from 1.5 to 3.5. Elimination of the expansion shocks with the C-D nozzle is shown to greatly improve the thrust vectoring; elimination of turning shocks with the skewed profile nozzle further improves the vectoring.

592. BEVILAQUA, P. M.; LEE, J. D.: **Design of a supersonic Coanda jet nozzle.** AIAA PAPER 84-0333 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 16 p. 84A18026

The thrust vectoring of supersonic Coanda jets was improved by designing a nozzle to skew the initial jet velocity profile. A new nozzle design procedure, based on the method of characteristics, was developed to design a nozzle which produces a specified exit velocity profile. The thrust vectoring of a simple convergent nozzle, a convergent-divergent nozzle, and a nozzle which produces a skewed velocity profile matched to the curvature of the Coanda surface were experimentally compared over a range of pressure ratios from 1.5 to 3.5. Elimination of the expansion shocks with the C-D nozzle is shown to greatly improve the thrust vectoring; elimination of turning shocks with the skewed profile nozzle further improves the vectoring.

4.7 SINGLE EXPANSION RAMP NOZZLE (SERN)

593. FLUGSTAD, T. H.; ROMINE, B. M.; WHITTAKER, R. W.: **High Mach exhaust system concept scale model test results.** AIAA PAPER 90-1905 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 26th, Orlando, FL, July 16-18, 1990. 8 p. 90A40552

The results of a scale model test of the Two-Dimensional Convergent-Divergent (2DCD) and Two-Dimensional Single Expansion Ramp Nozzle (SERN) configurations are presented to assess the performance, to establish geometric design criteria, and to validate advanced computational fluid dynamics codes for Mach 4 to 6 applications. The major conclusions derived are that the peak performance for all systems is comparable to the existing lower Mach nozzle designs; the ejector pumping performance is, in general, comparable to the existing ejector nozzle performance; and the predicted performance was consistently below levels of the performance measured in the scale model test. The nozzles tested are considered viable candidates for high Mach applications, and the test data provide an extensive design data base.

594. YAMAMOTO, K. J.; DONELSON, M. J.; WLEZIEN, R. W. **Supersonic jet noise reduction by a porous single expansion ramp nozzle**. AIAA PAPER 90-0366 AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 10 p. Research supported by the McDonnell Douglas Independent Research and Development Program. 1990. 90A19815

A shock noise reduction concept for supersonic rectangular jets is investigated for high speed civil transport (HSCT) applications. The noise reduction efficiency of a porous single external expansion ramp nozzle (SERN) with a 5:1 aspect ratio is experimentally investigated at both design and off-design pressure ratios. Porosity is implemented as a regular array of discrete holes in the ramp surface. Near- and far-field acoustic measurements, axial static pressure profiles, and Schlieren flow visualization are used to characterize the noise reduction mechanisms of the porous ramp. Solid ramp configurations are shown to dramatically reduce screech tones relative to a free rectangular jet. Surface porosity produces additional noise reduction by decreasing shock cell strength and consequently the magnitude of shock-associated noise. At a typical takeoff condition, approximately three EPNL dB reduction is estimated with 8 percent porosity ramp relative to no-ramp configuration.

595. CAPONE, FRANCIS J.; BARE, E. ANN, HEAD, VERLON E.: **Effects of multifunction nozzle installations on supersonic aeropropulsive characteristics of a supersonic fighter aircraft (U).** NASA-TP-2703 L-16246 NAS 1.60:2703 1987. 87X10508 <u>US GOV AGENCIES AND CONTRACTORS</u>

The aeropropulsive characteristics of an advanced twin-engine fighter designed for supersonic cruise were investigated in the Lewis 10- by 10-foot Supersonic Tunnel. The objectives of this investigation were to evaluate (1) the installed performance of advanced multifunction nozzles, (2) the effects of thrust-induced forces on overall aircraft aerodynamic performance, and (3) trim characteristics. Three multifunction nozzles were tested and included a two-dimensional convergent-divergent (2-D C-D) nozzle, a single expansion ramp nozzle (SERN), and a wedge nozzle. An axisymmetric nozzle was also tested for use as a reference. Thrust vectoring capability was also provided for the 2-D C-D nozzle and the SERN. The use of thrust vectoring or a canard for trim was also assessed. This investigation was conducted at Mach numbers from 2.00 to 2.47 at angles of attack from 0 deg to about 18 deg. Nozzle pressure ratio was varied from about 1 (jet off) to 32, depending on Mach number and nozzle power setting. (U)

596. DUSA, D. J.; SPEIR, D. W.; ROWE, R. K.; LEAVITT, L. D.: **Advanced technology exhaust nozzle development**. AIAA PAPER 83-1286 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle,WA, June 27-29, 1983. 17 p. 83A38080

The requirement for greater tactical aircraft operational capabilities has led to increasing research emphasis on the refinement of engine/airframe integration methods and exhaust nozzle flexibility. A major prospective advancement in the development of these capabilities takes the form of multifunctional exhaust nozzle systems with thrust reversal and thrust vectoring features, whose operation will be shared by both airframe and powerplant control systems. Attention is presently given to the two-dimensional convergent-divergent and single expansion ramp nozzle designs, with emphasis on the variable geometry mechanical systems by which they assume cruising flight, vectoring, and thrust reversal operations. The nozzles have been wind tunnel model-tested for the cases of the F-18 fighter and a supersonic cruise configuration concept.

597. CAPONE, F. J.; REUBUSH, D. E.: **Effects of varying podded nacelle-nozzle installations on transonic aeropropulsive characteristics of a supersonic fighter aircraft.** NASA-TP-2120 L-15525 NAS 1.60:2120 1983. 83N26821

The aeropropulsive characteristics of an advanced twin engine fighter designed for supersonic cruise was investigated in the 16 foot Transonic Tunnel. The performance characteristics of advanced nonaxisymmetric

nozzles installed in various nacelle locations, the effects of thrust induced forces on overall aircraft aerodynamics, the trim characteristics, and the thrust reverser performance were evaluated. The major model variables included nozzle power setting; nozzle duct aspect ratio; forward, mid, and aft nacelle axial locations; inboard and outboard underwing nacelle locations; and underwing and overwing nacelle locations. Thrust vectoring exhaust nozzle configurations included a wedge nozzle, a two dimensional convergent divergent nozzle, and a single expansion ramp nozzle, each with deflection angles up to 30 deg. In addition to the nonaxisymmetric nozzles, an axisymmetric nozzle installation was also tested. The use of a canard for trim was also assessed.

598. CAPONE, F. J.; HUNT, B. L.; POTH, G. E.: **Subsonic/supersonic nonvectored aeropropulsive characteristics of nonaxisymmetric nozzles installed on an F-18 model.** AIAA PAPER 81-1445 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 12 p. 81A40878

An experimental program on a model of the F-18 airplane has been conducted to determine the performance of nonaxisymmetric nozzles relative to the aircraft's baseline axisymmetric nozzle at Mach numbers from 0.60 to 2.20. The performance of a two-dimensional convergent-divergent nozzle, a single expansion ramp nozzle (ADEN) and a wedge nozzle were compared to the baseline axisymmetric nozzles. The nonaxisymmetric nozzles (except ADEN) were designed for vectoring and reversing. The axisymmetric nozzle did not have these capabilities. The comparisons presented here are for the nozzles in their full forward thrust mode and for the aircraft at zero angle of attack. The results demonstrate that nonaxisymmetric nozzles can be installed on a close-spaced twin engine fighter with equal or higher performance than the axisymmetric nozzle over the range of Mach numbers tested.

4.8 OTHER NOZZLES

599. BERRIER, BOBBY L.; TAYLOR, JOHN G.: **Internal performance of two nozzles utilizing gimbal concepts for thrust vectoring.** NASA-TP-2991 L-16722 NAS 1.60:2991 1990. 90N19200

The internal performance of an axisymmetric convergent-divergent nozzle and a nonaxisymmetric convergent-divergent nozzle, both of which utilized a gimbal type mechanism for thrust vectoring was evaluated in the Static Test Facility of the Langley 16-Foot Transonic Tunnel. The nonaxisymmetric nozzle used the gimbal concept for yaw thrust vectoring only; pitch thrust vectoring was accomplished by simultaneous deflection of the upper and lower divergent flaps. The model geometric parameters investigated were pitch vector angle for the axisymmetric nozzle and pitch vector angle, yaw vector angle, nozzle throat aspect ratio, and nozzle expansion ratio for the nonaxisymmetric nozzle. All tests were conducted with no external flow, and nozzle pressure ratio was varied from 2.0 to approximately 12.0.

600. TAYLOR, JOHN G.: Internal performance of a hybrid axisymmetric/ nonaxisymmetric convergent-divergent nozzle. NASA-TM-4230 L-16816 NAS 1.15:4230 1990. 90X36108 NASA PERS. ONLY

An investigation has been conducted in the static test facility of the Langley 16-foot transonic tunnel to determine the internal performance of a hybrid axisymmetric/nonaxisymmetric nozzle in forward-thrust mode. Nozzle cross-sections in the spherical convergent section were axisymmetric whereas cross-sections in the divergent flap area nonaxisymmetric (two-dimensional). Nozzle concepts simulating dry and afterburning power settings were investigated. Both subsonic cruise and supersonic cruise expansion ratios were tested for the dry power nozzle concepts. A/B power configurations were tested at an expansion ratio typical for subsonic acceleration. The spherical convergent flaps were designed in such a way that the transition from axisymmetric to nonaxisymmetric cross-section occurred in the region of the nozzle throat. Three different nozzle throat geometries were tested for each nozzle power setting. High-pressure air was used to simulate jet exhaust at nozzle pressure ratios up to 12.0.

601. HADDAD, A.: **Supersonic nozzle design of arbitrary cross-section.** 1988. 90N21035

An investigation, both theoretical and experimental in nature, was undertaken to develop a simple method for the design of supersonic nozzles and, indeed, inlets of quite complex shapes from known or calculated axisymmetric flow fields. The axisymmetric flowfield is determined using a computer program based on the method of characteristics. Streamlines are calculated by direct integration of the axisymmetric stream function. The desired shape is chosen at the exit of the computed axisymmetric nozzle having the desired length and Mach number. Its describing points are then traced along the corresponding streamlines back to the throat. Stream sheets formed by these streamlines define the new shape.

Following this approach, two three-dimensional nozzles were designed: one of elliptical cross-section and a two-dimensional wedge. Flows within the two configurations were further simulated using a general purpose three-dimensional CFD code, 'PHOENICS' (Parabolic, hyperbolic, or elliptic numerical integration code series), while the elliptical nozzle was subsequently manufactured and submitted to experimental tests. Results from the experimental tests and three-dimensional numerical simulation, as well as predictions of the performance of the nonaxisymmetric nozzles and their axisymmetric counterparts were obtained and compared. Good agreement was achieved between the several components of the study demonstrating that it is possible, using this relatively simple method, to design satisfactory three-dimensional nozzles.

602. CAPONE, FRANCIS J.; BARE, E. ANN, HEAD, VERLON E.: **Effects of multifunction nozzle installations on supersonic aeropropulsive characteristics of a supersonic fighter aircraft (U).** NASA-TP-2703 L-16246 NAS 1.60:2703 1987. 87X10508 <u>US GOV AGENCIES AND CONTRACTORS</u>

The aeropropulsive characteristics of an advanced twin-engine fighter designed for supersonic cruise were investigated in the Lewis 10- by 10-foot Supersonic Tunnel. The objectives of this investigation were to evaluate (1) the installed performance of advanced multifunction nozzles, (2) the effects of thrust-induced forces on overall aircraft aerodynamic performance, and (3) trim characteristics. Three multifunction nozzles were tested and included a two-dimensional convergent-divergent (2-D C-D) nozzle, a single expansion ramp nozzle (SERN), and a wedge nozzle. An axisymmetric nozzle was also tested for use as a reference. Thrust vectoring capability was also provided for the 2-D C-D nozzle and the SERN. The use of thrust vectoring or a canard for trim was also assessed. This investigation was conducted at Mach numbers from 2.00 to 2.47 at angles of attack from 0 deg to about 18 deg. Nozzle pressure ratio was varied from about 1 (jet off) to 32, depending on Mach number and nozzle power setting. (U)

603. YEZZI, C. A.; DONGUY, P.: **Thrust vector control technology demonstration.** AIAA PAPER 86-1642 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd, Huntsville, AL, June 16-18, 1986.6 p. 86A42767

The design and testing of the supersonic splitline nozzle for thrust vector control (TVC) is examined. The advantages of the splitline nozzle manufactured with C-C materials are discussed. The test motor and nozzle designs, which consist of a steel heavy-wall motor case, a blast tube, and a wired end-burning grain of reduced-smoke HTPB propellant are described. A motor with a ballistic nozzle in a standard thrust stand and a motor with a supersonic splitline nozzle in a multicomponent thrust stand were tested. Pressure versus time and thrust vector angle versus time are evaluated. For the ballistic nozzle a burn time of 1 sec longer than approximated and an accurate equilibrium surface were observed. The supersonic splitline nozzle data revealed the pressure trace is similar to baseline, and the thrust vector angle ratio is greater than 1.0 over the mechanical vector angle range from 0-18 deg. It is noted that the supersonic splitline nozzle with C-C material is aerodynamically applicable and weight effective for TVC.

604. YEZZI, C. A.; ANDERSON, C. W.; DONGUY, P.: **Thrust vector technology demonstration.** 1985. 86N17384

Atlantic Research Corporation (ARC), in a joint effort with Societe Europeenne de Propulsion (SEP) of France, funded the design and demonstration testing of advanced thrust vector control (TVC) concepts: one of these concepts was the supersonic splitline nozzle. The thrust vector control test was performed in the ARC multicomponent thrust stand with the baseline ballistic motor testing being performed in a standard (axial) thrust stand. The supersonic splitline nozzle is a very promising concept developed in the 1960's but abandoned due to material limitations; recent developments in nozzle materials justify further development of the concept. The supersonic splitline nozzle is a very attractive concept in that it offers vector deflection angle augmentation. An advanced lightweight, high temperature composite material manufactured by SEP was selected for use in both the throat and exit cone of the nozzle tested at ARC. Descriptions of motor and the thrust vector control system design, test set-up and test results are presented.

605. LILLEY, J. S.; HOFFMAN, J. D.: **Performance analysis of scarfed nozzles** . (AIAA, SAE, and ASME, Joint Propulsion Conference, 20th,Cincinnati, OH, June 11-13, 1984, AIAA Paper 84-1416) Journal of Spacecraft and Rockets (ISSN 0022-4650), vol. 23, Jan.-Feb. 1986, p. 55-62. Previously cited in issue 17, p. 2442, Accession no. 84A36978. 86A24035

606. JUNGCLAUS, G.: **Computation of the thrust vector of obliquely cut supersonic nozzles.** (Deutsche Gesellschaft fuer Luft- und Raumfahrt, Sitzung, Ottobrunn, West Germany, Dec. 7, 8, 1982) Zeitschrift fuer Flugwissenschaften und Weltraumforschung (ISSN 0342-068X), vol. 8, Mar.-Apr. 1984, p. 110-112. In German. 84A34719

The axial and lateral thrust of supersonic nozzles with rotational symmetry and obliquely cut exits is calculated using a simplified approximation technique in stream-tube theory. The results are compared with those for side-deflected rotationally symmetric and obliquely cut plane nozzles and confirmed by experimental measurements.

607. KRAIKO, A. N.; SHELOMOVSKII, V. V.: **Contouring of axisymmetric and plane nozzles for radial supersonic flow.** Akademiia Nauk SSSR, Izvestiia, Mekhanika Zhidkosti i Gaza, Jan.-Feb. 1983, p. 118-124. In Russian. 83A27713

The design of two types of supersonic nozzle configurations for uniform radial flow is described. The first type of configuration is designed in the form of 'radial' axisymmetric nozzles. The second type is designed as a set of N identical plane nozzles forming a star-shaped cascade. The Mach number in the outlet section of the nozzle and the radius at which annular or slotted minimal sections are situated are fixed. The generatrices of the supersonic parts are contoured in such a way that the radius of the annular outlet section is minimal.

4.9 JET NOISE

608. AHUJA, K. K.: **Controlling plume deflection by acoustic excitation - An experimental demonstration.** AIAA PAPER 90-4006 AIAA, Aeroacoustics Conference, 13th, Tallahassee, FL, Oct. 22-24, 1990. 12 p. Research supported by Georgia Institute of Technology and Lockheed Corp. 1990. 91A12519

Effect of imposing an external sound field on a Coanda jet was investigated experimentally. It was found that the exhaust angle of a Coanda plume can be varied by changing the level of excitation. Limited experiments were also performed in a wind tunnel to study the effects of flight simulation on plume deflection controllability by sound using a hollow airfoil fitted with a Coanda jet. Pressure coefficients are measured over this airfoil with and without acoustic excitation of the Coanda Jet. This exploratory study provided a number of new ideas for future work for controlling flow over curved surfaces.

609. KREJSA, EUGENE A.; COOPER, BETH A.; HALL, DAVID G.; KHAVARAN, ABBAS: **Noise measurements from an ejector suppressor nozzle in the NASA Lewis 9- by 15-foot low speed wind tunnel.** NASA-TM-103628 E-5717 NAS 1.15:103628 AIAA-90-3983 1990. 91N11493

Acoustic results are presented of a cooperative nozzle test program between NASA and Pratt and Whitney, conducted in the NASA-Lewis 9 x 15 ft Anechoic Wind Tunnel. The nozzle tested was the P and W Hypermix Nozzle concept, a 2-D lobed mixer nozzle followed by a short ejector section made to promote rapid mixing of the induced ejector nozzle flow. Acoustic and aerodynamic measurements were made to determine the amount of ejector pumping, degree of mixing, and noise reduction achieved. A series of tests were run to verify the acoustic quality of this tunnel. The results indicated that the tunnel test section is reasonably anechoic but that background noise can limit the amount of suppression observed from suppressor nozzles. Also, a possible internal noise was observed in the air supply system. The P and W ejector suppressor nozzle demonstrated the potential of this concept to significantly reduce jet noise. Significant reduction in low frequency noise was achieved by increasing the peak jet noise frequency. This was accomplished by breaking the jet into segments with smaller dimensions than those of the baseline nozzle. Variations in ejector parameters had little effect on the noise for the geometries and the range of temperatures and pressure ratios tested.

610. YAMAMOTO, K. J.; DONELSON, M. J.; WLEZIEN, R. W. **Supersonic jet noise reduction by a porous single expansion ramp nozzle.** AIAA PAPER 90-0366 AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 10 p. Research supported by the McDonnell Douglas Independent Research and Development Program. 1990. 90A19815

A shock noise reduction concept for supersonic rectangular jets is investigated for high speed civil transport (HSCT) applications. The noise reduction efficiency of a porous single external expansion ramp nozzle (SERN) with a 5:1 aspect ratio is experimentally investigated at both design and off-design pressure ratios. Porosity is implemented as a regular array of discrete holes in the ramp surface. Near- and far-field acoustic measurements, axial static pressure profiles, and Schlieren flow visualization are used to characterize the noise

reduction mechanisms of the porous ramp. Solid ramp configurations are shown to dramatically reduce screech tones relative to a free rectangular jet. Surface porosity produces additional noise reduction by decreasing shock cell strength and consequently the magnitude of shock-associated noise. At a typical takeoff condition, approximately three EPNL dB reduction is estimated with 8 percent porosity ramp relative to no-ramp configuration.

611. BRAUSCH, J. F.; MOTSINGER, R. E.; HOERST, D. J.: **Simulated flight acoustic investigation of treated ejector effectiveness on advanced mechanical suppressors for high velocity jet noise reduction.**: NASA-CR-4019 E-3134 NAS 1.26:4019 R85AEB518 1986. 87N17481

Ten scale-model nozzles were tested in an anechoic free-jet facility to evaluate the acoustic characteristics of a mechanically suppressed inverted-velocity-profile coannular nozzle with an acoustically treated ejector system. The nozzle system used was developed from aerodynamic flow lines evolved in a previous contract, defined to incorporate the restraints imposed by the aerodynamic performance requirements of an Advanced Supersonic Technology/Variable Cycle Engine system through all its mission phases. Acoustic data of 188 test points were obtained, 87 under static and 101 under simulated flight conditions. The tests investigated variables of hardwall ejector application to a coannular nozzle with 20-chute outer annular suppressor, ejector axial positioning, treatment application to ejector and plug surfaces, and treatment design. Laser velocimeter, shadowgraph photograph, aerodynamic static pressure, and temperature measurement were acquired on select models to yield diagnostic information regarding the flow field and aerodynamic performance characteristics of the nozzles.

612. SIMONICH, J. C.; AMIET, R. K.; SCHLINKER, R. H.: **Jet shielding of jet noise.** NASA-CR-3966 NAS 1.26:3966 1986. 86N25219

An experimental and theoretical study was conducted to develop a validated first principle analysis for predicting the jet noise reduction achieved by shielding one jet exhaust flow with a second, closely spaced, identical jet flow. A generalized fuel jet noise analytical model was formulated in which the acoustic radiation from a source jet propagates through the velocity and temperature discontinuity of the adjacent shielding jet. Input variables to the prediction procedure include jet Mach number, spacing, temperature, diameter, and source frequency. Refraction, diffraction, and reflection effects, which control the dual jet directivity pattern, are incorporated in the theory. The analysis calculates the difference in sound pressure level between the dual jet configuration and the radiation field based on superimposing two independent jet noise directivity patterns. Jet shielding was found experimentally to reduce noise levels in the common plane of the dual jet system relative to the noise generated by two independent jets.

613. KIBENS, V.; WLEZIEN, R. W.: **Noise reduction mechanisms in supersonic jets with porous centerbodies.** (American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 8th, Atlanta, GA, Apr. 11-13, 1983, AIAA Paper 83-0774) AIAA Journal (ISSN 0001-1452), vol. 23, May 1985, p. 678-684. Previously cited in issue 10, p. 1378, Accession no. 83A25959. 1985. 85A32606

614. CARPENTER, P. W.: **A linearized theory for swirling supersonic jets and its application to shock-cell noise.** (AIAA, Fluid and Plasma Dynamics Conference, 13th, Snowmass, CO, July 14-16, 1980, AIAA Paper 80-1449) AIAA Journal (ISSN 0001-1452), vol. 23, Dec. 1985, p. 1902-1909. Previously cited in issue 17, p. 3174, 80A41628. 1985. 86A17137

615. TAM, C. K. W.: **On broadband shock associated noise of supersonic jets: Recent advances in aeroacoustics** (87A11766 02-71). New York, Springer-Verlag, 1986, p. 25-51. 87A11768

The characteristics and generation mechanisms of noise associated with the interactions of turbulence with the quasi-periodic broadband shock cells of supersonic jet engines are reviewed. The noise possesses broadband spectra and directionality that are completely different from noise caused by turbulence. Experimental data have shown that broadband noise is most prominent in the forward arc, with peak frequencies being a function of the observation angle and the pressure mismatch in the engine. The noise originates in the engine as turbulence-shock interactions occur during downstream movement. Features of the phased point-source array model and the large turbulence structures-shock cells interaction model are defined and model predictions are compared with experimental data on noise sources. Only a scaling of the noise component is found to be currently possible. More complete characterization depends on consideration of the jet temperature and analysis of turbulence-shock interactions, broadband shock and screech tones and shock noise in several flow configurations.

616. DASH, R.: **Flight effects on noise from coaxial dual flow. II - Heated jets.** AIAA Journal (ISSN 0001-1452), vol. 24, June 1986, p. 940-947. 86A41708

This paper is a continuation of the study described in Part I and deals with the flight effects on noise from heated jets. The present work shows that coaxial exhaust flows with inverted profiles are much quieter than flows with conventional profiles. Among all possible coaxial configurations with only one of the streams heated conventional profile, inverted profile, and the variable stream control engine (VSCE) cycle - and holding constant mass flow and thrust, a VSCE cycle is the best possible engine cycle as it provides over 18-dB reduction in sound pressure level (as compared to noise from a conventional profile cycle) a tall angles, both statically and in flight. The study also indicates that, if both the coaxial streams are heated unequally, a duct-burning profile, combined with the variable stream control engine (DB-VSCE) concept, gives rise to a powerful coaxial device which generates the least noise, both statically and in flight. This concept will be of paramount importance as one of the most variable nozzle designs of the future.

617. STONE, J. R.: **Supersonic jet shock noise reduction.** NASA-TM-83799 E-2299 NAS 1.15:83799 1984. 84N35085

Shock-cell noise is identified to be a potentially significant problem for advanced supersonic aircraft at takeoff. Therefore NASA conducted fundamental studies of the phenomena involved and model-scale experiments aimed at developing means of noise reduction. The results of a series of studies conducted to determine means by which supersonic jet shock noise can be reduced to acceptable levels for advanced supersonic cruise aircraft are reviewed. Theoretical studies were conducted on the shock associated noise of supersonic jets from convergent-divergent (C-D) nozzles. Laboratory studies were conducted on the influence of narrow band shock screech on broadband noise and on means of screech reduction. The usefulness of C-D nozzle passages was investigated at model scale for single-stream and dual-stream nozzles. The effect of off-design pressure ratio was determined under static and simulated flight conditions for jet temperatures up to 960 K. Annular and coannular flow passages with center plugs and multi-element suppressor nozzles were evaluated, and the effect of plug tip geometry was established. In addition to the far-field acoustic data, mean and turbulent velocity distributions were measured with a laser velocimeter, and shadowgraph images of the flow field were obtained.

618. STONE, J. R.: **Supersonic jet shock noise reduction.** AIAA PAPER 84-2278 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 9th, Williamsburg, VA, Oct. 15-17, 1984. 44 p. Previously announced in STAR as 84N35085. 85A16099

Shock-cell noise is identified to be a potentially significant problem for advanced supersonic aircraft at takeoff. Therefore NASA conducted fundamental studies of the phenomena involved and model-scale experiments aimed at developing means of noise reduction. The results of a series of studies conducted to determine means by which supersonic jet shock noise can be reduced to acceptable levels for advanced supersonic cruise aircraft are reviewed. Theoretical studies were conducted on the shock associated noise of supersonic jets from convergent-divergent (C-D) nozzles. Laboratory studies were conducted on the influence of narrow band shock screech on broadband noise and on means of screech reduction. The usefulness of C-D nozzle passages was investigated at model scale for single-stream and dual-stream nozzles. The effect of off-design pressure ratio was determined under static and simulated flight conditions for jet temperatures up to 960 K. Annular and coannular flow passages with center plugs and multi-element suppressor nozzles were evaluated, and the effect of plug tip geometry was established. In addition to the far-field acoustic data, mean and turbulent velocity distributions were measured with a laser velocimeter, and shadowgraph images of the flow field were obtained.

619. NORUM, T. D.: **Screech suppression in supersonic jets.** (American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 20th, Orlando, FL, Jan. 11-14, 1982, AIAA 82-0050.) AIAA Journal,vol. 21, Feb. 1983, p. 235-240. 83A19814

(Previously cited in issue 06, p. 941, Accession no. 82A17753)

620. SHEARIN, J. G.: **Investigation of jet-installation noise sources under static conditions.** NASA-TP-2181 L-15599 NAS 1.61:21811983. 83N33684

The acoustical effects of operating a 6-cm exit-diameter nozzle in the presence of a wing-flap model under static conditions are examined experimentally. The geometric parameters of the wing-flap model are chosen to represent a realistic jet-engine installation on a wide-body midrange transport airplane. The effects of varying the installation parameters and the noise sources associated with the engine-installation effects are discussed. The major noise sources are the flow interaction of the jet and wing

undersurface, the flow interaction of the jet with the side edges of the flap cutout and flap trailing edge, and the reflection of the jet noise off the undersurface of the wing and flap.

621. TAM, C. K. W.; TANNA, H. K.: **Shock associated noise of supersonic jets from convergent-divergent nozzles**. Journal of Sound and Vibration, vol. 81, Apr. 8, 1982, p. 337-358. Research supported by the Lockheed Internal Research and Development Funds. 82A32202

Experimental and theoretical results are presented on the characteristics of shock-associated noise from imperfectly expanded supersonic jets from convergent-divergent nozzles over an extensive range of underexpanded and overexpanded operating conditions. The source of this noise is believed to be the weak but coherent interaction between the downstream-propagating large-scale turbulent flow structures in the mixing layer of the jet and the nearly periodic shock cell system. Reasoning based on this mechanism leads to the scaling formula that the intensity of shock-associated noise varies as (Mj-squared minus Md-squared)-squared, where Mj and Md are the fully expanded jet operating Mach number and the nozzle design Mach number, respectively. A peak frequency formula is also derived from the same model. The noise intensity, directivity, and spectra of supersonic jets from a convergent-divergent nozzle of design Mach number 1.67 were measured in an anechoic chamber over the Mach number range of 1.1 to 2.0. Theoretical results agree very favorably with measurements.

622. NORUM, T. D.: **Screech suppression in supersonic jets**. AIAA PAPER 82-0050 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 20th, Orlando, FL, Jan. 11-14, 1982, 9 p. 82A17753

Jet screech from underexpanded sonic nozzles has been investigated experimentally. Multiple screech modes, or stages, are found to be present at some jet operating conditions. The fundamental screech tone of each mode attains a maximum amplitude at about 20 deg from the inlet axis, with higher harmonics exhibiting multiple lobes. The directivity of each harmonic is predicted quite well from a stationary array of acoustic monopoles, with phasing between consecutive monopoles determined by the shock cell spacing and eddy convection velocity. Large reduction of screech amplitude can be obtained from modifications to the nozzle exit, although the extent of this suppression is mode dependent.

623. WAT, J.; SAROHIA, V.: **Flight effects on supersonic convergent-divergent nozzle jet noise**. AIAA PAPER 81-2027 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 7th, Palo Alto, CA, Oct. 5-7, 1981, 9 p. 81A49728

The influence of forward flight on the noise generation from convergent-divergent (C-D) nozzle flows was determined experimentally. The experiments were performed in an anechoic chamber using a 2.03 cm diameter C-D nozzle with a design Mach number of 1.4 in a 25 cm diameter free jet flow. Far-field noise measurements and spectral analyses were carried out and visualization of the jet shock structure was made by a spark shadowgraph technique. Jet noise from supersonic C-D nozzle flows under forward flight was found to depend critically on the flight velocity and nozzle pressure ratio. Noise reduction up to 20 dB was observed in the rearward quadrant under flight; excess noise in the forward quadrant underflight resulted from relatively high frequency noise sources in the jet flow field. Screech tones, observed from overexpanded C-D nozzle flows, were suppressed during the simulated flight flow.

624. KOWALSKI, E. J.; PEERY, K. M.; KLEES, G. W.: **Numerical simulation for the design of a supersonic cruise nozzle with a fluid noise shield.** AIAA PAPER 81-1218 American Institute of Aeronautics and Astronautics, Fluid and Plasma Dynamics Conference, 14th, Palo Alto, CA, June 23-25, 1981, 9 p. 81A39006

A two-dimensional/axisymmetric flow analysis procedure is used to simulate the plug nozzle flow field with an acoustic shield. Using this flow analysis, the unexpectedly low shield nozzle discharge coefficients are explained and the optimum offset between the shield nozzle and primary nozzle exit planes for maximum shield nozzle discharge coefficient is then determined. The purpose is to illustrate the utility of a flow analysis procedure for interpreting experimental flow data and for acquiring design information for a nozzle system of current interest.

625. SEINER, J. M.; NORUM, T. D.: **Aerodynamic aspects of shock containing jet plumes.** AIAA PAPER 80-0965 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 6th, Hartford, Conn., June 4-6, 1980, 18 p. 80A43600

Aerodynamic and acoustic measurements of shock-free and shock-containing plumes were acquired for several supersonic free-jet model nozzles. The purpose was to investigate important features of the broadband shock noise generation process. The aerodynamic measurements include the variation of shock cell spacing and strength as

a function of nozzle pressure ratio, and longitudinal turbulent-mass-flux axial development as determined by a hot-film probe. In addition, correlations of the hot-film probe with a near-field microphone were obtained. These measurements provide useful information concerning the relation of peak shock noise frequency and level with variations in shock cell spacing and strength. In general, it is shown that a distinction must be made between plumes containing weak and strong imbedded shocks. Strong shocks diminish the level of emitted shock noise and influence the behavior of the jet mixing noise process. The probable location and spectral content for the shock-shear layer interaction mechanism is indicated by the correlations. Numerical inviscid plume comparisons with experimental data are also included.

626. STONE, J. R.; MONTEGANI, F. J.: **An improved prediction method for the noise generated in flight by circular jets**. NASA-TM-81470 E-403 1980. 80N22048

A semi-empirical model for predicting the noise generated by jets exhausting from circular nozzles is presented and compared with small-scale static and simulated-flight data. The present method is an updated version of that part of the original NASA aircraft noise prediction program relating to circular jet noise. The earlier method agreed reasonably well with experimental static and flight data for jet velocities up to approximately 520 m/sec. The poorer agreement at higher jet velocities appeared to be due primarily to the manner in which supersonic convection effects were formulated. The purely empirical supersonic convection formulation is replaced in the present method by one based on theoretical considerations. Other improvements of an empirical nature were included based on model-jet/free-jet simulated-flight tests. The effects of nozzle size, jet velocity, jet temperature, and flight are included.

627. CARPENTER, P. W.: **A linearised theory for swirling supersonic jets and its application to shock-cell noise.** AIAA PAPER 80-1449 American Institute of Aeronautics and Astronautics, Fluid and Plasma Dynamics Conference, 13th, Snowmass, Colo., July 14-16, 1980, 10 p. 80A41628

A linearized theory is developed for underexpanded inviscid supersonic jets with arbitrary initial swirl. The radial displacement of a given stream line from its position at nozzle exit is used as the dependent variable. The governing equation is fairly complicated and has to be solved numerically by the method of characteristics. A simple expression for the wavelength of the primary shock cell is derived. The linearized theory is used to extend some of Howe and Ffowcs Willaims theoretical results for shock-associated noise to swirling supersonic jets. In this way estimates are made of the effect of swirl on the total radiated sound power of shock-associated noise. It is found that for a certain type of swirl the shock-associated noise could be greatly reduced, or even eliminated, for sufficiently high swirl levels. This could be achieved at the expense of a very small thrust loss.

628. AHUJA, K. K.; TANNA, H. K.; TESTER, B. J.: **Effects of simulated forward flight on jet noise, shock noise and internal noise**. AIAA PAPER 79-0615 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 5th, Seattle, Wash., Mar. 12-14, 1979, 11 p. 1979. 79A26936

Inflight simulation experiments are conducted in an anechoic free-jet facility to examine the flight effects on various combinations of jet noise, shock noise and internal noise. The jet mixing noise component reduces with forward velocity at all angles and frequencies. When jet mixing noise is contaminated with internal noise, forward motion provides a noise reduction in the rear arc and a noise increase in the forward arc, with little change at 90 deg. The results are similar for shock-containing jets. It is found that the existing anomalies between full-scale flight data and model-scale flight simulation data could well be due to the contamination of the flight data by internal noise.

629. CLAUSS, J. S., JR.; WRIGHT, B. R.; BOWIE, G. E.: **Twinjet noise shielding for a supersonic cruise vehicle.** AIAA PAPER 79-0670 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 5th, Seattle, Wash., Mar. 12-14, 1979, 11 p. 1979. 79A28971

An engine arrangement for a supersonic cruise vehicle (SCV) has been developed that shows promise for jet noise reduction without the performance penalties associated with mechanical suppressors and engine oversizing. This arrangement, wherein two engines are placed on top of the wing directly above two similarly-mounted engines below the wing, can produce 3 to 5 dB less noise below the aircraft flight path than when four engines are installed under the wing. This noise reduction is due to acoustic shielding of the upper jets by the lower jets. Test data are reviewed to verify this acoustical shielding phenomenon, and detailed takeoff trajectories are calculated to show the effects of sideline and flyover noise levels on constraining maximum range SCV configurations. Engine placement variation and differential throttling, wherein thrust is unloaded from the lower

engine and added to the upper engine, are to be explored as means for maximizing the shielding effect.

630. KOZLOWSKI, H.: **Coannular nozzle noise characteristics and application to advanced supersonic transport engines.** In NASA. Langley Res. Center Proc. of the SCAR Conf., Pt. 2, 14 p (SEE 77N18019 09-01) 1976. 77N18021

Recent programs in the field of jet noise, sponsored by the NASA Lewis Research Center, have indicated that the variable stream control engines (VSCE) which are being considered for advanced supersonic cruise aircraft have inherent jet noise advantages over earlier engines. This characteristic is associated with the exit velocity profile produced by such an engine. The high velocity fan stream, on the outer periphery, is acoustically dominant while the primary stream is held to a low velocity and therefore contributes little to the overall noise. Scale model tests have indicated low noise levels. Operation under static conditions, as well as in a relative velocity field (simulating take-off speeds) has indicated large reductions are available from the coannular nozzle and the VSCE. The inherently low levels of jet noise prompted changes in the cycle, which allowed an increase in the amount of augmentation incorporated in the fan stream, without exceeding the suggested noise guidelines, thereby allowing the use of a considerably smaller engine, with obvious vehicle advantages.

631. BOESCH, H.; WOELFER, G.; KIEKEBUSCH, B.; SCHEERER, J.: **Theoretical and experimental investigation of noise shielding for jet engines.**: BMFT-FB-W-76-09 Aug. 1976 77N17072

Experimental investigations of the possibilities of shielding jet engine noise through changes to aircraft configuration were carried out with a 1:10 scale aircraft half-model. Several configurations with the engines mounted above the wing were investigated in a reflection free room. A fan model with nacelle having the same scale as the aircraft model was used as a noise source. The results from these investigations were used to optimize a computer program, developed for the Europlane project, for the calculation of noise emission from noise shielded configurations. In addition to the acoustic measurements, aerodynamic interference effects were investigated for noise shielded nacelle configurations on a typical transport aircraft having a transonic wing profile.

4.10 MIXERS AND EJECTORS

632. LORD, W. K., JONES, C. W., STERN, A. M., HEAD, V. L., KREJSA, E. A.: **Mixer ejector nozzle for jet noise suppression.** AIAA PAPER 90-1909 AIAA, SAE, ASME, ASEE, 26th Joint Propulsion Conference, Orlando, FL, July 16-18, 1990, 20 p. 1990. 90A47202

An aero/acoustic model of a mixer-ejector nozzle was conducted at the 9x15 foot low-speed acoustic wind tunnel at NASA Lewis Research Center. The objective of the test was to get a preliminary assessment of ejector pumping and noise reduction potential of this device for possible application in the exhaust system of an advanced supersonic civil transport. The results of the test showed that goal levels of pumping were achieved. Exit pressure/temperature traverse data showed that there was good mixing between the primary and secondary streams. Acoustics data were dominated by shock noise: jet mixing noise levels were low because of a facility limit on primary temperature. The mixer-ejector did significantly reduce shock noise relative to the baseline conic nozzle. Because the relative magnitudes of the jet mixing noise and shock noise were not in the correct proportion to properly model engine noise, an Effective Perceived Noise Level (EPNL) assessment was precluded.

633. CHOI, Y. H., SOH, W. Y.; **Computational analysis of a two-dimensional ejector nozzle.**: AIAA PAPER 90-1901 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 26th, Orlando, Fl, July 16-18, 1990, 16 p. 90N23406.

A time-iterative full Navier-Stokes code, PARC, is used to analyze the flowfield of a two-dimensional ejector nozzle.

634. ILLMAN, T. G.; PATERSON, R. W.; PRESZ, W. M., JR.: **Supersonic nozzle mixer ejector.** AIAA PAPER 89-2925 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 25th, Monterey, CA, July 10-13, 1989. 10 p. Research supported by United Technologies Corp. 89A47178

Experimental results are presented for the performance of a supersonic nozzle mixer-ejector representative of candidate devices for commercial SST noise attenuation during takeoff and landing. In this mixer-ejector configuration, an array of large-scale, low-intensity streamwise vortices is introduced into the downstream mixing duct; these enhance mixing through an inviscid-

mixing process yielding enhanced ejector pumping. A convergent/divergent, suitably lobed mixer nozzle was tested and its results compared with those for a conventional slot-nozzle ejector. The lobed nozzle is able to increase ejector pumping performance by 75 percent over the conventional nozzle.

635. FANG, RENSONG; ZHANG, RONGXUE: **Reduction of ejector noise with multihole nozzle.** Journal of Aerospace Power (ISSN 1000-8055),vol. 3, April 1988, p. 145-148, 188. In Chinese, with abstract in English. 89A11034

In order to reduce the noise, an ejector with a multihole nozzle is proposed as the primary nozzle, and its design method is presented. For comparison of the aerodynamic performance and the noise characteristics with those of conventional ones in subsonic and supersonic ejector systems, the sound power levels and the primary and secondary mass flow rates of the ejectors were measured, and the static thrusts of the ejectors were estimated, based on the measured mass flow rates. The shroud length of the ejector system tested was altered in the experiments so as to study the effect of this parameter on noise and thrust. The experimental results show that the multihole nozzle ejector system not only reduces noise considerably but also gains better aerodynamic performance due to a shorter shroud. The shorter the shroud, the more noise reduction and the greater the static thrust increment that can be achieved.

636. DEESE, J. E.; AGARWAL, R. K.: **A numerical study of viscous flow in inlets and augmentors.** AIAA PAPER 88-0187 AIAA, Aerospace Sciences Meeting, 26th, Reno, NV, Jan. 11-14, 1988. 8 p. 1988. 88A41092

Flowfields through two-dimensional and axisymmetric inlets and thrust-augmenting ejectors are modeled by use of the thin-layer approximation to the unsteady Reynolds-averaged Navier-Stokes equations. The equations are solved by an explicit multistage Runge-Kutta time-stepping method employing a finite-volume formulation on body-conforming curvilinear grids. Eddy viscosity models are used to describe turbulence effects. Results compare well with experimental data for transonic inlet flows. Improvements in turbulence modeling are needed for better prediction of ejector flowfields.

637. FEDERSPIEL, JOHN F.; KUCHAR, ANDREW P.: **Performance evaluation of a two dimensional convergent-divergent ejector exhaust system.** AIAA PAPER 88-2999 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 11 p. 88A46492

The results of a parametric test of two-dimensional convergent-divergent (2DCD) ejector nozzles are presented. Data were obtained from scale model cold flow testing. The geometries tested were representative of current technology aircraft engine nozzles. The thrust and pumping performance trends with geometry and with operating levels are shown and compared to those of axisymmetric ejector nozzles of similar geometry obtained from a statistical data base. The performance characteristics of axisymmetric ejector nozzles had been extensively investigated and well documented. However, very little test data existed for 2DCD ejector nozzles. The 2DCD nozzles showed slightly higher thrust levels but overall, comparisons were well within a range expected by statistical error. Pumping/air handling performance.

638. DUTTON, J. C.; CARROLL, B. F.: **Limitation of ejector performance due to exit choking.** ASME, Transactions, Journal of Fluids Engineering (ISSN 0098-2202), vol. 110, March 1988, p. 91-93. Research supported by the University of Illinois. 88A31266

A previous technique for determining optimized ejector performance and designs for a large class of practical problems is extended to include the phenomenon of mixed flow exit choking. The phenomena is shown to occur for relatively extreme combinations of molecular weight and stagnation temperatures, and to result in reduced ejector performance over that predicted from the well known Fabri inlet choking criterion. Optimization results are presented for these conditions.

639. SEAVER, CHRISTOPHER A.: **Ejector effects on a supersonic nozzle at low altitude and Mach number.** AD-A206049 AFIT/GAE/A88D-33 1988. 89N23427

This research involves the study of ejector effects on a supersonic nozzle. A blowdown wind tunnel was used to simulate the launch of an ejector rocket to determine possible thrust augmentation capabilities of such a design. Pressure measurements were made along the mixing chamber during the 42 separate runs which were used to select a specified profile to study the effects the flow has on wall pressures and rocket thrust. Primary airflow was directed to the primary rocket nozzle designed for Mach 3.09. Secondary airflow was directed to a sonic ejector which was adjusted to simulate vehicle Mach number. A vacuum tank was used to provide the environment simulating a reverse trajectory of a launch.

640. BRAUSCH, J. F.; MOTSINGER, R. E.; HOERST, D. J.: **Simulated flight acoustic investigation of treated ejector effectiveness on advanced mechanical suppressors for high velocity jet noise reduction.** :NASA-CR-4019 E-3134 NAS 1.26:4019 R85AEB518 1986. 87N17481

Ten scale-model nozzles were tested in an anechoic free-jet facility to evaluate the acoustic characteristics of a mechanically suppressed inverted-velocity-profile coannular nozzle with an acoustically treated ejector system. The nozzle system used was developed from aerodynamic flow lines evolved in a previous contract, defined to incorporate the restraints imposed by the aerodynamic performance requirements of an Advanced Supersonic Technology/Variable Cycle Engine system through all its mission phases. Acoustic data of 188 test points were obtained, 87 under static and 101 under simulated flight conditions. The tests investigated variables of hardwall ejector application to a coannular nozzle with 20-chute outer annular suppressor, ejector axial positioning, treatment application to ejector and plug surfaces, and treatment design. Laser velocimeter, shadowgraph photograph, aerodynamic static pressure, and temperature measurement were acquired on select models to yield diagnostic information regarding the flow field and aerodynamic performance characteristics of the nozzles.

641. SAMOILOVA, N. V.; SHUMILKINA, E. A.: **Thrust efficiency of an ejector with a supersonic nozzle.** TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 17, no. 3, 1986, p. 133-137. In Russian. 1986. 88A50052

Estimated performance characteristics are presented for an ejector thrust augmentor equipped with a supersonic nozzle, and a comparison is made with the characteristics of a converging-nozzle ejector thrust augmentor. Over the practically important range of critical nozzle cross sections and pressure ratios, the use of a supersonic nozzle is shown to provide a gain in thrust of up to 10 percent.

642. Oscillation of primary flow of a supersonic air ejector. JSME Bulletin (ISSN 0021-3764), Vol. 29, Oct. 1986, p. 3297-3302. 1986 87A27167

In the case of zero-secondary flow of a supersonic air ejector with a throat in its mixing section, the flow in the ejector oscillates for a particular range of the stagnation pressure of the primary flow. In the present paper, the flow oscillation is experimentally investigated by optical observations and pressure measurements. It is shown that an oscillation with a frequency of about 100-150Hz is superimposed on an oscillation with a frequency of about 5-6Hz, and that the former oscillation is caused by the jet from the primary nozzle oscillating vertically to the center line of the ejector. The mechanism of the flow oscillation is clarified taking the behavior of the jet from the primary nozzle and the variation of pressure in the secondary stagnation chamber into consideration

643. DUTTON, J. C.; CARROLL, B. F.: **Optimal supersonic ejector designs.** ASME PAPER 86-WFE-3 (ASME, Winter Annual Meeting, Anaheim, CA, Dec. 7-12, 1986) ASME, Transactions, Journal of Fluids Engineering (ISSN 0098-2202), vol. 108, Dec. 1986, p. 414-420. Research supported by the University of Illinois. 87A23203

A technique based on a one-dimensional constant area flow model has been developed for solving a large class of supersonic ejector optimization problems. In particular, the method determines the primary nozzle Mach number and ejector area ratio which optimizes either the entrainment ratio, compression ratio, or stagnation pressure ratio given values for the other two variables and the primary and secondary gas properties and stagnation temperatures. Design curves for the common case of diatomic primary and secondary gases of equal molecular weight and stagnation temperature are also presented and discussed.

644. BROOKE, D.; DUSA, D. J.; KUCHAR, A. P.; ROMINE, B. M.: **Initial performance evaluation of 2DCD ejector exhaust systems.** AIAA PAPER 86-1615 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd, Huntsville, AL, June 16-18, 1986. 11 p. 86A42753

An ejector nozzle system can furnish the cooling flow requirement of advanced nonaxisymmetric exhaust nozzles, perhaps yielding improvements in overall propulsion system performance. An equivalent area method is presently developed on the basis of an existing axisymmetric ejector nozzle prediction program for both nozzle performance (thrust coefficient) and the air-handling characteristics of the nonaxisymmetric designs considered. A scale test model program has been conducted to determine static performance and air handling for four different two-dimensional convergent/divergent exhaust systems. Results adequate for preliminary design studies are obtained.

645. NELSON, D. P.: **Model aerodynamic test results for a refined actuated inlet ejector nozzle at simulated takeoff and cruise conditions comprehensive data report. Volume 1: Design drawings.** NASA-CR-168052-Vol-1 NAS 1.26:168052-Vol-1 PWA-5768-30-VOL-1 1983. 83X10239 US GOV AGENCIES AND CONTRACTORS

Wind tunnel model tests were conducted to demonstrate the aerodynamic performance improvements of a refined actuated inlet ejector nozzle. Models of approximately one-tenth scale were configurated to simulate nozzle operation at takeoff, subsonic cruise, transonic cruise and supersonic cruise. Variations of model components provided a performance evaluation of ejector inlet and exit area, forebody boattail angle and ejector inlet operation in the open and closed mode. Approximately 700 data points were acquired at Mach numbers of 0, 0.36, 0.9, 1.2, and 2.0 for a wide range of nozzle flow conditions. Results show that relative to two ejector nozzles previously tested performance was improved significantly at takeoff and subsonic cruise. Takeoff quiescent and fly-over performance was improved 0.3 and 1.6 percent respectively. At subsonic cruise a 4.2 percent improvement was demonstrated. Good supersonic cruise performance, a C(f) of 0.982, was attained equal to the high performance of the previous tests. The established advanced supersonic transport propulsion study performance goals were met or closely approached at takeoff and supersonic cruise. Subsonic cruise performance was within 2.3 percent of the target. Design drawings of the nozzle model are presented.

646. NELSON, D. P.; BRESNAHAN, D. L.: **Ejector nozzle test results at simulated flight conditions for an advanced supersonic transport propulsion system.**: AIAA PAPER 83-1287 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 11 p. 83A36323

Results are presented of wind tunnel tests conducted to verify the performance improvements of a refined ejector nozzle design for advanced supersonic transport propulsion systems. The analysis of results obtained at simulated engine operating conditions is emphasized. Tests were conducted with models of approximately 1/10th scale which were configured to simulate nozzle operation at takeoff, subsonic cruise, transonic cruise, and supersonic cruise. Transonic cruise operation was not a consideration during the nozzle design phase, although an evaluation at this condition was later conducted. Test results, characterized by thrust and flow coefficients, are given for a range of nozzle pressure ratios, emphasizing the thrust performance at the engine operating conditions predicted for each flight Mach number. The results indicate that nozzle performance goals were met or closely approximated at takeoff and supersonic cruise, while subsonic cruise performance was within 2.3 percent of the goal with further improvement possible.

647. SHEN, H.; DONG, C.; SHYUR, T.; KEE, M.: **The sweep finite element method for calculating the flow field and performance of supersonic ejector nozzles.** In: International Symposium on Air Breathing Engines, 5th, Bangalore, India, February 16-22, 1981, Proceedings. (81A29051 12-07) Bangalore, National Aeronautical Laboratory, 1981, p. 15-1 to 15-5. 81A29061

A new method is presented to calculate the performance and the flow field of supersonic ejector nozzles. As compared with previous methods, this method treats the subsonic, transonic and supersonic flow of the nozzle with a more general and yet simpler calculating procedure. By means of the method of weighted residuals, the governing differential equations of aerodynamics are transformed directly into nonlinear algebraic equations. Certain optimization techniques are used for solving these equations. By starting from the upstream side and by considering each element as an independent calculating unit, the calculation is carried on from one element to another. Computations were made and the numerical results are compared with those of the method of characteristics and with appropriate experimental data. Comparison shows that they are in fairly satisfactory agreement.

648. HUILI, S.; ZHONGGING, C.: **Analytical and experimental investigation of performance of supersonic ejector nozzles.** AD-A118279 FTD-ID(RS)T-0347-82 1982. 83N11090

An analytical method for calculating the flow field and performance of supersonic ejector nozzles is presented. The calculations involve the real sonic line at the exit of the primary nozzle, the inviscid primary flow field, the correction for the viscosity effect, the pumping characteristic, and the thrust characteristic.

649. PAULON, J.; PERUCCHINI, J.: **Testing ventilated nozzle models with supersonic primary flow.** In its La Rech. Aerospatiale, Bimonthly Bull. No. 1981-3, May-Jun. 1981, (ESA-TT-714), p 75-79 (See 82N19152 10-01) 1981. 82N19159

Ventilated nozzles, i.e., aircraft engine ejectors with, at the periphery of the engine flux, a low rate flow from a circuit different from that passing through the compressor, the combustion chamber and the turbine, are considered. Theoretical schemes that take precise and correct account of the evolution of the two fluxes in order to deduce nozzle efficiency and jet engine thrust are examined. Simplifying hypotheses are discussed and tests carried out in an aerothermodynamic laboratory to confirm them are described. Results define the domain of influence of downstream disturbances which can modify nozzle performance.

650. TSHEN, H.; CHEN, Z.: **Analytical and experimental investigation of supersonic ejector nozzles.** (Recent selected papers of Northwestern Polytechnical University. Part 1, p. 51-64.) Engineering Thermophysics in China, vol. 1, Oct.-Dec. 1981, p. 399-412. Translation. 82A16250

(For abstract see issue 05, p. 649, Accession no. 81A17806)

651. IV, A.; WOLFSHTEIN, M.: **Numerical solution of a supersonic ejector pump.** (Israel Annual Conference on Aviation and Astronautics, 22nd, Tel Aviv and Haifa, Israel, Mar. 12, 13, 1980.) Israel Journal of Technology, vol. 18, no. 1-2, 1980, p. 104-111. 81A35939

A supersonic ejector pump is considered. The performance of the system is studied by a combination of a one-dimensional non-viscous and an axially-symmetric turbulent method; The results show that the performance of the system may be improved by increasing the stagnation pressure and temperature of the primary fluid, or by lowering the viscosity of the secondary fluid.

652. MATSUO, K.; MOCHIZUKI, H.; SASAGUCHI, K.; TASAKI, K. **Investigation of supersonic air ejectors.** I - Performance in the case of zero-secondary flow JSME, Bulletin, vol. 24, Dec. 1981, p. 2090-2097. 1981. 82A22210

Zero-secondary flow behavior is examined, and the physical meaning of the performance diagrams of supersonic second-throat air-ejectors is defined. Vacuum characteristics of the ejector are investigated experimentally over a range of primary nozzle Mach numbers and throat area ratios. It is shown that an optimum throat area ratio exists for each Mach number of the primary nozzle, in which case the vacuum performance of the ejector becomes maximum with a minimum stagnation pressure of the primary flow. Modification of a previous method for the case of a constant-area mixing tube (Addy and Chow, 1964) allow for calculation of the ejector performance for a variable-area mixing tube in the case of a larger throatarea ratio than the optimum one. Calculated results are found to agree well with experimental ones.

653. LOPEZ, A. E.; KOENIG, D. G.; GREEN, D. S.; NAGARAJA, K. S.: **Workshop on Thrust Augmenting Ejectors.** NASA-CP-2093 A-7887 1979. 80N10107

654. SHEN, H.; CHEN, Z.: **Analytical and experimental investigation of performance of supersonic ejector nozzle.** Recent selected papers of Northwestern Polytechnical University. Part 1. (81A17801 05-01) Xian, Shaanxi, People's Republic of China, Northwestern Polytechnical University, 1979, p. 51-64. In Chinese, with abstract in English. 1979. 81A17806

An analytical method for calculating the flow field and performance of a supersonic ejector nozzle is presented. Calculations involve the real sonic line at the exit of the primary nozzle, the inviscid primary flow field, the correction for the viscosity effect and pumping, and thrust characteristics. Calculations were performed on a digital computer, and model tests were performed in a ground test facility. Analytical and experimental results agree fairly well.

655. AIKEN, T. N.; FALARSKI, M. D.; KOENIN, D. G.: **Aerodynamic characteristics of a large-scale semispan model with a swept wing and an augmented jet flap with hypermixing nozzles** NASA-TM-73236 A-7013 1979. 79N29144

The aerodynamic characteristics of the augmentor wing concept with hypermixing primary nozzles were investigated. A large-scale semispan model in the Ames 40-by 80-Foot Wind Tunnel and Static Test Facility was used. The trailing edge, augmentor flap system occupied 65% of the span and consisted of two fixed pivot flaps. The nozzle system consisted of hypermixing, lobe primary nozzles, and BLC slot nozzles at the forward inlet, both sides and ends of the throat, and at the aft flap. The entire wing leading edge was fitted with a 10% chord slat and a blowing slot. Outboard of the flap was a blown aileron. The model was tested statically and at forward speed. Primary parameters and their ranges included angle of attack from -12 to 32 degrees, flap angles of 20, 30, 45, 60 and 70 degrees, and deflection and diffuser area ratios from 1.16 to 2.22. Thrust coefficients ranged from 0 to

2.73, while nozzle pressure ratios varied from 1.0 to 2.34. Reynolds number per foot varied from 0 to 1.4 million. Analysis of the data indicated a maximum static, gross augmentation of 1.53 at a flap angle of 45 degrees. Analysis also indicated that the configuration was an efficient powered lift device and that the net thrust was comparable with augmentor wings of similar static performance.

4.11 THERMAL ACOUSTIC SHIELDS

656. BEDIAKO, E. D.; WAGENKNECHT, C. D.: **Aerodynamic performance investigation of thermal acoustic shield nozzle.** NASA-CR-174867 NAS 1.26:174867 R83AEB121-3 1985. 85X10255 DOMESTIC

A nonintrusive noise reduction thermal acoustic shield (TAS) exhaust nozzle concept applicable to an advanced supersonic transonic transport (AST) propulsion system was devised. Interest in this concepts stems from its potential for reducing jet noise by partially surrounding the high velocity main jet exhaust with a hot, low velocity gas shield. A model test program was conducted to determine the effects of shield gas implementation apparatus on takeoff aerodynamic performance as well as the effect of the stowed shield on nontakeoff performance. The losses associated with shield gas implementation and its wider implication on the AST mission if such losses could be eliminated or minimized are examined. The TAS and other AST exhaust systems are compared.

657. JOHNSON, P.; KLEES, G.: **Acoustic shield design study.** In its Advan. Concept Studies for Supersonic Vehicles, 16 p (See 82X10002 01-01) 1981. 82X10015 US GOV AGENCIES AND CONTRACTORS

A mechanical design study was conducted to validate the feasibility of integrating a TAS jet-noise suppressor in the GE21/J11-B19 engine nozzle. The TAS system installation increased the radius of the lower half of the nozzle. The maximum envelope radius is increased by about 7.6 cm (3.0 in) with TAS closed resulting in a pod drag increase of 0.4% of total airplane drag. The TAS provides a 7.1 cm (2.8 in) shield thickness for a 180 deg wrap. The 180 deg wrap requires 15% of the core stream airflow at a velocity that is 62% of the equivalent mixed flow primary jet. A 7% thrust loss occurs at the same power setting when the shield is deployed; however, oversizing the engine is not required because the engine is sized by transonic thrust margin. The shield causes a loss in internal performance amounting to 0.1% of nozzle thrust coefficient at cruise because of roughness and leakage. Pod weight increase by 346 kg (763 lb) per pod at the reference airflow size of 349 kg/s (770 lb/s). The total airplane range penalty is 185 km (100 nmi).

658. PICKUP, N.; MANGIAROTTY, R. A.; OKEEFE, J. V.: **Tests of a thermal acoustic shield with a supersonic jet.** AIAA PAPER 81-2021 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 7th, Palo Alto, CA, Oct. 5-7, 1981, 13 p. 81A48623

Fuel economy is a key element in the design of a future supersonic transport (SST). Variable cycle engines are being developed to provide the most economic combination of characteristics for a range of cruise speeds extending from subsonic speeds for overland flights to the supersonic cruise speeds. For one of these engines, the VCE-702, some form of noise suppression is needed for takeoff/sideline thrusts. The considered investigation is primarily concerned with scale model static tests of one particular concept for achieving that reduction, the thermal acoustic shield (TAS), which could also benefit other candidate SST engines. Other noise suppression devices being considered for SST application are the coannular nozzle, an internally ventilated nozzle, and mechanical suppressors. A test description is provided, taking into account the model configurations, the instrumentation, the test jet conditions, and aspects of screech noise control. Attention is given to shield thickness effects, a spectrum analysis, suppression and performance loss, and installed performance.

659. PICKUP, N.; MANGIAROTTY, R. A.; OKEEFE, J. V.: **Tests of a thermal acoustic shield with a supersonic jet.** (American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 7th, Palo Alto,CA, Oct. 5-7, 1981, Paper 81-2021.) Journal of Aircraft, vol. 19, Nov. 1982, p. 940-946. 83A10183

660. JANARDAN, B. A.; BRAUSCH, J. F.; MAJJIGI, R. K.: **Freejet feasibility study of a thermal acoustic shield concept for AST/VCE application: Dual stream nozzles.** NASA-CR-3867 E-2392 NAS 1.26:38671985. 87N10752

The influence of selected geometric and aerodynamic flow variables of an unsuppressed coannular plug nozzle and a coannular plug nozzle with a 20-chute outer stream suppressor were experimentally determined. A total of 136 static and simulated flight acoustic test points were conducted with 9 scale model nozzles. Also, aerodynamic

measurements of four selected plumes were made with a laser velocimeter. The presence of the 180 deg shield produced different mixing characteristics on the shield side compared to the unshield side because of the reduced mixing with ambient air on the shielded side. This resulted in a stretching of the jet, yielding a higher peak mean velocity up to a length of 10 equivalent diameters from the nozzle exit. The 180 deg shield in community orientation around the suppressed coannular plug nozzle yielded acoustic benefit at all observer angles for a simulated takeoff. While the effect of shield-to-outer stream velocity ratio was small at angles up to 120 deg, beyond this angle significant acoustic benefit was realized with a shield-to-outer stream velocity ratio of 0.64.

661. JANARDAN, B. A.; BRAUSCH, J. F.; MAJJIGI, R. K.: **Freejet feasibility study of a thermal acoustic shield concept for AST/VCE application: Dual stream nozzles.** NASA-CR-3867 E-2392 NAS 1.26:38671985. 87N10752

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662. JANARDAN, B. A.; BRAUSCH, J. F.; PRICE, A. O.: **Free-jet feasibility study of a thermal acoustic shield concept for AST/VCE application-dual stream nozzles. Comprehensive data report. Volume 2: Laser velocimeter and suppressor. Base pressure data.** NASA-CR-174818 NAS 1.26:174818 R84AEB570 1984. 86N23372

Acoustic and diagnostic data that were obtained to determine the influence of selected geometric and aerodynamic flow variables of coannular nozzles with thermal acoustic shields are summarized in this comprehensive data report. A total of 136 static and simulated flight acoustic test points were conducted with 9 scale-model nozzles. Aerodynamic laser velocimeter measurements were made for four selected plumes. In addition, static pressure data in the chute base region of the suppressor configurations were obtained to assess the influence of the shield stream on the suppressor base drag.

663. JANARDAN, B. A.; BRAUSCH, J. F.; PRICE, A. O.: **Free jet feasibility study of a thermal acoustic shield concept for AST/VCE application-dual flow. Comprehensive data report. Volume 1: Test nozzles and acoustic data.** NASA-CR-174817 NAS 1.26:174817 R84AEB5701984. 86N23371

Acoustic and diagnostic data that were obtained to determine the influence of selected geometric and aerodynamic flow variables of coannular nozzles with thermal acoustic shields are summarized in this comprehensive data report. A total of 136 static and simulated flight acoustic test points were conducted with 9 scale-model nozzles The tested nozzles included baseline (unshielded), 180 deg shielded, and 360 deg shielded dual flow coannular plug configurations. The baseline configurations include a high radius ratio unsuppressed coannular plug nozzle and a coanuular plug nozzle and a coannular plug nozzle with a 20-chute outer stream suppressor. The tests were conducted at nozzle temperatures and pressure typical of operating conditions of variable cycle engine.

664. GOODYKOONTZ, J.: **Effect of a semi-annular thermal acoustic shield on jet exhaust noise.** Acoustical Society of America, Meeting, 100th, Los Angeles, Calif., Nov. 17-21, 1980, Paper. 19 p. 81A22532

The effect of a semi-annular acoustic shield on jet exhaust noise is investigated with the rationale that such a configuration would reduce or eliminate the multiple reflection mechanism. A limited range of flow conditions for one nozzle/shield configuration were studied at model scale. Noise measurements for a 10 cm conical nozzle with a semi-annular acoustical shield are presented in terms of loss less free field data at various angular locations with respect to the nozzle. Measurements were made on both the shielded and unshielded sides of the nozzle. Model scale overall sound pressure level directivity patterns and comparisons of model scale spectral data are provided. The results show that a semi-annular thermal acoustic shield consisting of a low velocity, high temperature gas stream partially

surrounding a central jet exhibits lower noise levels than when the central jet is operated alone. The results are presented parametrically, showing the effects of various shield and central system velocities and temperatures.

4.12 MECHANICAL NOISE SUPPRESSORS

665. FITZSIMMONS, R. D.; MCKINNON, R. A.; JOHNSON, E. S.; BROOKS, J. R.: **Flight and wind tunnel test results of the mechanical jet noise suppressor nozzle.** AIAA PAPER 80-0165 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 49 p. 80A20971

Comprehensive acoustic and propulsion data are presented, based on flight and wind tunnel tests, of a mechanical jet noise suppressor designed to satisfy the requirements of an advanced supersonic transport (AST) under study by the McDonnell Douglas Corporation. The flight program was conducted jointly by MDC, Rolls-Royce Ltd., and the British Aerospace Corporation, using an HS-125 aircraft modified to accept an upgraded RR Viper 601 engine with conical reference and mechanical suppressor nozzles and an acoustically treated ejector. The nacelle, engine and nozzle configurations from the HS-125 were also tested in one of NASA's wind tunnels to obtain thrust performance at forward velocity and acoustic data. The acoustic flight test data, when scaled to an AST engine nozzle size and projected to a typical sideline distance, indicate reduction in effective perceived noise level of 16 EPNdB at the takeoff power setting. It is estimated that the in-flight thrust loss for a typical AST suppressor/ejector nozzle configuration (37.5 inch equivalent diameter) would be 5.4 percent at takeoff power settings and 6.6 percent at cutback power settings.

666. BRAUSCH, J. F.; MOTSINGER, R. E.; HOERST, D. J.: **Simulated flight acoustic investigation of treated ejector effectiveness on advanced mechanical suppressors for high velocity jet noise reduction.** NASA-CR-4019 E-3134 NAS 1.26:4019 R85AEB518 1986. 87N17481

Ten scale-model nozzles were tested in an anechoic free-jet facility to evaluate the acoustic characteristics of a mechanically suppressed inverted-velocity-profile coannular nozzle with an acoustically treated ejector system. The nozzle system used was developed from aerodynamic flow lines evolved in a previous contract, defined to incorporate the restraints imposed by the aerodynamic performance requirements of an Advanced Supersonic Technology/Variable Cycle Engine system through all its mission phases. Acoustic data of 188 test points were obtained, 87 under static and 101 under simulated flight conditions. The tests investigated variables of hardwall ejector application to a coannular nozzle with 20-chute outer annular suppressor, ejector axial positioning, treatment application to ejector and plug surfaces, and treatment design. Laser velocimeter, shadowgraph photograph, aerodynamic static pressure, and temperature measurement were acquired on select models to yield diagnostic information regarding the flow field and aerodynamic performance characteristics of the nozzles.

667. FITZSIMMONS, R. D.; MCKINNON, R. A.; JOHNSON, E. S.; BROOKS, J. R.: **Flight and wind tunnel test results of the mechanical jet noise suppressor nozzle.** AIAA PAPER 80-0165 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 49 p. 80A20971

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668. VONGLAHN, U.: **Acoustic considerations of flight effects on jet noise suppressor nozzles.** NASA-TM-81377 E-282 AIAA-PAPER-80-0164 1979. 80N14843

The in flight acoustic characteristics of high velocity jet noise suppressor nozzles for supersonic cruise aircraft were reviewed. The in flight effects at the peak noise

level were discussed. Both single and inverted velocity profile multistream suppressor nozzles were considered. The importance of static spectral shape on the noise reduction due to inflight effects was stressed.

669. FITZSIMMONS, R. D.; MCKINNON, R. A.; JOHNSON, E. S.; BROOKS, J. R.: **Flight and wind tunnel test results of the mechanical jet noise suppressor nozzle.** AIAA PAPER 80-0165 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 49 p. 80A20971

Comprehensive acoustic and propulsion data are presented, based on flight and wind tunnel tests, of a mechanical jet noise suppressor designed to satisfy the requirements of an advanced supersonic transport (AST) under study by the McDonnell Douglas Corporation. The flight program was conducted jointly by MDC, Rolls-Royce Ltd., and the British Aerospace Corporation, using an HS-125 aircraft modified to accept an upgraded RR Viper 601 engine with conical reference and mechanical suppressor nozzles and an acoustically treated ejector. The nacelle, engine and nozzle configurations from the HS-125 were also tested in one of NASA's wind tunnels to obtain thrust performance at forward velocity and acoustic data. The acoustic flight test data, when scaled to an AST engine nozzle size and projected to a typical sideline distance, indicate reduction in effective perceived noise level of 16 EPNdB at the takeoff power setting. It is estimated that the in-flight thrust loss for a typical AST suppressor/ejector nozzle configuration (37.5 inch equivalent diameter) would be 5.4 percent at takeoff power settings and 6.6 percent at cutback power settings.

4.13 THRUST REVERSERS

670. MEHALIC, CHARLES M.; LOTTIG, ROY A.: **Full-scale thrust reverser testing in an altitude facility.** AIAA PAPER 87-1788 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 14 p. Previously announced in STAR as 87N18575. 87A45203

A two-dimensional convergent-divergent exhaust nozzle designed and fabricated by Pratt and Whitney Aircraft was installed on a PW1128 turbofan engine and tested during thrust reverser operation in an altitude facility at NASA Lewis Research Center. A unique collection system was used to capture the thrust reverser exhaust gas and transport it to the primary exhaust collector. Tests were conducted at three flight conditions with varying amounts of thrust reverse at each condition. Some reverser exhaust gas spillage by the collection system was encountered but engine performance was unaffected at all flight conditions tested. Based on the results of this test program, the feasibility of altitude testing of advanced multifunction exhaust nozzle systems has been demonstrated.

671. MEHALIC, CHARLES M.; LOTTIG, ROY A.: **Full-scale thrust reverser testing in an altitude facility.** NASA-TM-88967 AIAA-87-1788 E-3435 NAS 1.15:88967 1987. 87N18575

A two-dimensional convergent-divergent exhaust nozzle designed and fabricated by Pratt and Whitney Aircraft was installed on a PW1128 turbofan engine and tested during thrust reverser operation in an altitude facility at NASA Lewis Research Center. A unique collection system was used to capture the thrust reverser exhaust gas and transport it to the primary exhaust collector. Tests were conducted at three flight conditions with varying amounts of thrust reverse at each condition. Some reverser exhaust gas spillage by the collection system was encountered but engine performance was unaffected at all flight conditions tested. Based on the results of this test program, the feasibility of altitude testing of advanced multi-function exhaust nozzle systems has been demonstrated.

672. THAYER, E. B.: **Thrust reverser-exhaust nozzle assembly for a gas turbine engine.** AD-D012390 US-PATENT-4,591,097US-PATENT-APPL-SN-611041US-PATENT-CLASS-239-265.29 1986. 87N12561

This patent discloses an improved thrust reverser/exhaust nozzle assembly which has a plurality of blocker devices located in the divergent section of the exhaust nozzle and a plurality of deflector devices located in the convergent section of the nozzle. The blocker and deflector devices are linked together such that they move simultaneously and maintain a substantially constant engine between forward and reverse thrust conditions.

673. TSYBIZOV, IU. I.; SALMANOVA, N. G.: **Study of clamshell reverser operation downstream of nozzle** (Aviatsionnaia Tekhnika, vol. 22, no. 3, 1979, p. 119-122.) Soviet Aeronautics, vol. 22, no. 3, 1979, p.108-110. Translation. 80A47443

Reversers with clamshells located downstream of the propulsive nozzle exit section are used on some aircraft. This paper presents an experimental study of such reversers for the purpose of making a proper selection of

geometrical dimensions and investigating the effects of structural characteristics on the design parameters. In particular, attention was given to the magnitude of the reverse thrust of the scoop slope, the relative distance from the reverser clamshells to the nozzle exit plane, and the presence of a slot between the clamshells along the nozzle axis.

4.14 NOZZLE DESIGN

674. NACHSHON, Y.: **Simple and accurate calculation of supersonic nozzle contour.** AIAA Journal (ISSN 0001-1452), vol. 21, May 1983, p. 783,784. 1983. 83A28971

The method of characteristics is commonly used to design a supersonic nozzle. This method is widely applied to large nozzles where the boundary-layer displacement thickness is small compared to the nonviscous flow. As the nozzle becomes larger and the Mach number higher, it is necessary to use more characteristics lines in order to achieve an accurate supersonic profile. Such a profile is needed to obtain a uniform flowfield at the exit of the nozzle in the supersonic test chamber. The present investigation is concerned with a simple method which considerably increases the accuracy of the solution for a given number of characteristics lines.

675. ETO, K.; MATSUOKA, M.; FUKUOKA, O.: **Study on design of a supersonic nozzle.** I - Improvement of a calculating method for a flowfield of mixed type JSME, Bulletin (ISSN 0021-3764), vol. 28, July 1985, p. 1396-1400. 86A10480

The flowfield inside a nozzle is analyzed under both upstream and downstream boundary conditions using a series expansion procedure of the velocity components. The analysis is confined to the two-dimensional case.The results are consistent with those from other authors and from experiment.

676. DENISENKO, O. V.: **Method for the design of supersonic nozzles in the case of a strong viscosity effect.** TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 13, no. 4, 1982, p. 71-80. In Russian. 83A37558

A method is proposed for the design of supersonic nozzles with allowance for viscosity. This method is applicable in a wide range of Reynolds numbers and makes it possible to contour nozzles in the case when the thickness of the laminar boundary layer is comparable to or even greater than the transverse dimension of the inviscid core. When necessary, the design can be carried out with allowance for various effect of second order or smallness. As an example, calculations for the case of gamma = 1.4 and Pr = 0.715 are considered.

677. MEAUZE, G.; FOURMAUX, A.: **A coupled inverse-inverse method for over-expanded supersonic nozzles.** ONERA, TP NO. 1985-109IN: International Symposium on Air Breathing Engines, 7th, Beijing, People's Republic of China, September 2-6, 1985, Proceedings (86A11601 02-07). New York, AIAA, 1985, p. 45-49. 86A11605

An inverse-inverse coupling method is proposed for taking into account internal flow separations occurring in supersonic nozzles in overexpanded regimes. First, various coupling techniques are briefly reviewed, and a justification is given for the proposed approach. The application to supersonic nozzles is then discussed in more detail, with computations for different overexpanded configurations included.

4.15 NOZZLE FLOWS

678. BOWMAN, H. L.; GUTMARK, E.; SCHADOW, K. C.; WILSON, K. J.; SMITH, R. A.: **Supersonic rectangular isothermal shrouded jets.** AIAA PAPER 90-2028 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 26th, Orlando, FL, July 16-18, 1990. 12 p. 90A40599

The entrainment characteristics of shrouded flows utilizing supersonic shrouded circular or rectangular converging/diverging jets were investigated using a free jet test facility with interchangeable supersonic circular or 3 to 1 aspect ratio rectangular nozzles with a design Mach number of 2.0. Entrained flow velocity was measured at the shroud inlet, and the mass flow ratios were computed for different shroud lengths and diameters. It was found that rectangular jets with supersonic divergence on the major axis or on both axes induced higher entrained flow velocities and mass flow ratios compared to the circular jet, or a rectangular jet with divergence only on the minor axis.

679. GUIDICE, P. D.: **Analysis of three-dimensional supersonic nozzle exhaust flow fields.** LAR-11596. 90M10318

A second order numerical method employing reference plane characteristics has been developed for the calculation of geometrically complex three dimensional nozzle-exhaust flow fields, heretofore uncalculable by existing methods. The nozzles may have irregular cross sections with swept throats and may be stacked in modules using the vehicle undersurface for additional expansion. The nozzles may have highly nonuniform entrance conditions, the medium considered being an equilibrium hydrogen-air mixture. The program calculates and carries along the underexpansion shock and contact as discrete discontinuity surfaces, for a nonuniform vehicle external flow. Additionally, shock formation due to coalescence is detected. A wide variety of geometric problems may be considered since the reference plane method has been developed for three separate coordinate systems, all incorporated into a single program. This program is written in FORTRAN IV for batch execution and has been implemented on a CDC 6000 Series computer. This program was developed in 1972.

680. RENCH, E. P.: **EXHAUST PLUME START LINE PROGRAM.** MSC-17682 90M10820

The program computes the flow properties at the exit of a supersonic nozzle based upon incomplete knowledge of the nozzle flow field. It verifies the extrapolated portion by applying the conservation of mass principle. A correlation has been found useful in the computation of plume start lines (right-running characteristics emanating from a rocket nozzle lip). For all engines examined, the initial portion of the start line exhibits a linear variation of flow angle versus ray angle with a slope near one. Plume start line calculations are carried out using the equations for the changes in nozzle flow and the radial and axial coordinates along a right-running characteristic. In addition, linear and parabolic equations are used to relate flow angle along the characteristic to the ray angle determined by the coordinates. Mass flow crossing the start line is computed and compared with throat mass flow as a check on the overall correctness of the start line calculation. The computer program can extrapolate partial start lines or generate lines based on approximate relationships. It can use available thermodynamic tables or generate tables from the properties of the gas constituents. The program has been used to obtain approximate start lines from limited geometrical data. Its results agree very closely with those obtained by method-of-characteristics programs.

681. ZHAO, JINGYUN: **Effect of geometric parameters on internal performance of convergent-divergent nozzle.** Journal of Aerospace Power (ISSN 1000-8055), vol. 4, July 1989, p. 273, 274, 295. In Chinese, with abstract in English. 89A52320

The effect of geometric parameters on internal performance of convergent-divergent nozzle has been investigated experimentally. The relationships of thrust coefficient and wall static pressure distribution to area ratio, divergent angle, convergent angle, and throat radius of curvature are presented in this paper.

682. WLEZIEN, R. W.: **Nozzle geometry effects on supersonic jet interaction.** (AIAA, Aeroacoustics Conference, 11th, Sunnyvale, CA, Oct. 19-21, 1987, AIAA Paper 87-2694) AIAA Journal (ISSN 0001-1452), vol. 27, Oct. 1989, p. 1361-1367. Research supported by McDonnell Douglas Independent Research and Development Program. Previously cited in issue 04, p. 569, Accession no. 88A16548. 89A53932

683. DUTTON, J. C.: **Correlation of nozzle performance degradation due to swirl.** Journal of Propulsion and Power (ISSN 0748-4658), vol. 5, Jan.-Feb. 1989, p. 126-128. 1989. 89A22295

An attempt is made to identify a 'universal' swirl number, and to represent correlations for the mass flow and thrust performance parameters of supersonic propulsion nozzles with swirling flow. This parameter ideally collapses the discharge coefficient, thrust efficiency, and specific impulse efficiency curves for various nozzle geometries and tangential velocity profiles onto single universal curves when used as the independent variable.

684. HANG, CHAU-LYAN; KRONZON, YIGAL; MERKLE, CHARLES L.: **Time-iterative solutions of viscous supersonic nozzle flows.** (AIAA, Fluid Dynamics, Plasma Dynamics, and Lasers Conference, 19th, Honolulu, HI, June 8-10, 1987, AIAA Paper 87-1289) AIAA Journal (ISSN 0001-1452), vol. 26, Oct. 1988, p. 1208-1215. USAF-sponsored research. Previously cited in issue 18, p. 2806, Accession no. 87A42364. 1988. 89A20184

685. CARPENTER, P. W.: **The effects of swirl on the performance of supercritical convergent-divergent nozzles.** Aeronautical Quarterly, vol. 32, May 1981, p. 126-152. 1981. 81A36999

Quasi-one-dimensional theory is applied to supercritical swirling flows with uniformly constant stagnation pressure and entropy in convergent-divergent nozzles. Values of exit impulse function and area ratio are given for various types of swirling flow with a range of back-pressure ratios, and thrust coefficients are calculated using these values and specific thrust coefficients plotted against maximum swirl velocity for various cases. The effects of nozzle wall curvature and flight speed on swirling nozzle flows are discussed, and the contribution of post-exit thrust to the total thrust is estimated. Implications of the use of swirl at the cruise conditions of a typical SST are considered.

686. DIDIIATULINA, F. L.; LAVRUKHIN, G. N.; MICHAILOV, B. N.; TAGIROV, R. K.; IAGUDIN, S. V.: **Computational and experimental investigations of the influence of the contour curvature radius in the throat region on supersonic nozzle characteristics.** TsAGI, Uchenye Zapiski, vol. 11, no. 4, 1980, p. 159-164. In Russian. 1980. 81A35921

Characteristics of nine supersonic nozzles with different curvature radii are investigated. Examined values of the nozzle geometric parameters correspond to the range which is characteristic of controlled jet-engine nozzles. Static pressure distributions on the walls of subsonic and supersonic nozzle parts, the discharge coefficient, and the relative impulse are determined. Experimental investigations were conducted in a pressure chamber with unheated air being used as the working medium. Results show that a decrease of the contour curvature radius (R) in the nozzle region from R = 1 to R = 0 results in a reduction of the nozzle discharge coefficient; and it practically does not change the nozzle relative impulse coefficient. Calculation results agree with experimental results.

4.16 NOZZLE AFTERBODY FLOWFIELD

687. COMPTON, WILLIAM B., III; ABDOL-HAMID, KHALED S.: **Navier-Stokes simulation of transonic afterbody flows with jet exhaust.**: AIAA PAPER 90-3057 IN: AIAA Applied Aerodynamics Conference, 8th, Portland, OR, Aug. 20-22, 1990, Technical Papers. Part 1 (90A4584521-02). Washington, DC, American Institute of Aeronautics and Astronautics, 1990, p. 189-200. 1990. 90A45862

Three-dimensional Navier-Stokes simulations have been made for the transonic flow past a nonaxisymmetric nozzle typical of those advocated for advanced fighter airplanes. Jet exhaust simulation is evaluated as are the Baldwin-Lomax (1978) and Goldberg (1986) turbulence models. Solutions are presented for Mach numbers of 0.80 and 0.94 at 0-deg angle of attack and a Reynolds number of 20 x 10 to the 6th. The numerical results are compared to wind-tunnel data. They show that including the jet exhaust in the calculations gives the most accurate solution near the nozzle exit. Also, the two turbulence models predict considerably different flow fields.

688. STITT, LEONARD E.: **Exhaust nozzles for propulsion systems with emphasis on supersonic cruise aircraft.** NASA-RP-1235 E-4789 NAS 1.61:1235 1990. 90N21037

This compendium summarizes the contributions of the NASA-Lewis and its contractors to supersonic exhaust nozzle research from 1963 to 1985. Two major research and technology efforts sponsored this nozzle research work; the U.S. Supersonic Transport (SST) Program and the follow-on Supersonic Cruise Research (SCR) Program. They account for two generations of nozzle technology: the first from 1963 to 1971, and the second from 1971 to 1985.First, the equations used to calculate nozzle thrust are introduced. Then the general types of nozzles are presented, followed by a discussion of those types proposed for supersonic aircraft. Next, the first-generation nozzles designed specifically for the Boeing SST and the second-generation nozzles designed under the SCR program are separately reviewed and then compared. A chapter on throttle-dependent afterbody drag is included, since drag has a major effect on the off-design performance of supersonic nozzles. A chapter on the performance of supersonic dash nozzles follows, since these nozzles have similar design problems, Finally, the nozzle test facilities used at NASA-Lewis during this nozzle research effort are identified and discussed. These facilities include static test stands, a transonic wind tunnel, and a flying testbed aircraft. A concluding section points to the future: a third generation of nozzles designed for a new era of high speed civil transports to produce even greater advances in performance, to meet new noise rules, and to ensure the continuity of over two decades of NASA research.

689. HENDERSON, WILLIAM P.: **Propulsion-airframe integration for commercial and military aircraft.** SAE PAPER 872411 IN: International Pacific Air and Space Technology Conference, Melbourne, Australia, Nov. 13-17, 1987, Proceedings (89A1062701-01). Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 133-144. 89A10637

A significant level of research is ongoing at NASA's Langley Research Center on integrating the propulsion system with the aircraft. This program has included nacelle/pylon/wing integration for turbofan transports, propeller/nacelle/wing integration for turboprop transports, and nozzle/afterbody/empennage integration for high performance aircraft. The studies included in this paper focus more specifically on pylon shaping and nacelle location studies for turbofan transports, nacelle and wing contouring and propeller location effects for turboprop transports, and nozzle shaping and empennage effects for high performance aircraft. The studies were primarily conducted in NASA Langley's 16-Foot Transonic Tunnel at Mach numbers up to 1.20. Some higher Mach number data obtained at NASA's Lewis Research Center is also included.

690. HENDERSON, W. P.: **Propulsion/airframe integration: An overview** 1986. 86X10199 DOMESTIC

The Propulsion Airframe Integration Activities at the Langley Research Center addressed include: the integration of the nozzles with the afterbody of high-performance fighter type aircraft; the utilization of the nozzles to provide the fighter aircraft with enhanced capability by incorporating thrust vectoring and thrust reversing; the integration of turbofan nacelles with the wing and pylons; and the integration of turboprops in both the wing tractor and fuselage mounted pusher configurations.

691. MURTHY, S. N. B.; PAYNTER, G. C.: **Numerical methods for engine-airframe integration**. New York, American Institute of Aeronautics and Astronautics, Inc. (Progress in Astronautics and Aeronautics. Volume 102), 1986, 554 p. For individual items see 87A11777 to 87A11781. 1986. 87A11776

Various papers on numerical methods for engine-airframe integration are presented. The individual topics considered include: scientific computing environment for the 1980s, overview of prediction of complex turbulent flows, numerical solutions of the compressible Navier-Stokes equations, elements of computational engine/airframe integrations, computational requirements for efficient engine installation, application of CAE and CFD techniques to complete tactical missile design, CFD applications to engine/airframe integration, and application of a second-generation low-order panel methods to powerplant installation studies. Also addressed are: three-dimensional flow analysis of turboprop inlet and nacelle configurations, application of computational methods to the design of large turbofan engine nacelles, comparison of full potential and Euler solution algorithms for aeropropulsive flow field computations, subsonic/transonic, supersonic nozzle flows and nozzle integration, subsonic/transonic prediction capabilities for nozzle/afterbody configurations, three-dimensional viscous design methodology of supersonic inlet systems for advanced technology aircraft, and a user's technology assessment.

692. KEEN, K. S.: **Inexpensive calibrations for the influence function method using the interference distributed loads code.**: AIAA PAPER 85-0270 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 23rd, Reno, NV, Jan. 14-17, 1985. 5 p. USAF-supported research. 1985. 85A19623

Two engineering prediction methods for the calculation of store aerodynamic loads within the interference flow field of an aircraft have been integrated to produce a tool with capabilities beyond the range of either method individually. A reduction in computer cost of three-orders-of-magnitude has been realized in the theoretical determination of the influence response coefficient distributions of conventional store configurations. Additionally, nonlinear aerodynamic effects such as vortex downwash on the store afterbody were modeled. The integrated method has been incorporated into an interactive geometry modeling/input preparation system which allows a user with little or no familiarity with the related codes to derive the influence coefficient distributions with minimal effort. Predictions of store loads in an aircraft flow field using these influence coefficients have shown very good agreement with experimental data.

693. HARDY, J.-M.: **Exhaust system for combat aircraft optimized for supersonic cruise.** L'Aeronautique et l'Astronautique (ISSN 0001-9275), no. 104, 1984, p. 16-28. In French. 84A34172

The Concorde nozzle principle is described together with its calculation methods. Results from an optimization study of the internal structure of the Concorde ejector in supersonic cruise are analyzed, emphasizing the significance of the secondary pressure level in the selection of the primary ejector type and taking into consideration the hot gas effect during interpretation of wind tunnel data. Topics covered include techniques for supersonic cruise optimization; Mirage nozzles; calculations of the primary flow, of the flow in a two-flux ejector (short and long ejectors); the adaptation of the

afterbody to subsonic flight conditions; the effect of external parameters on afterbody performance; long ejectors for a primary convergent-divergent nozzle; biconic nozzles; and optimization of the propulsion system.

694. GRIEB, H.; VEDOVA, R.; ENDERLE, H.; NAGEL, H.: **Comparison of different nozzle concepts for a reheated turbofan.** 1981. 82N13077

Several concepts of convergent and convergent/divergent nozzles are investigated and compared in view of performance, weight, complexity and the influence on afterbody drag of combat aircraft. The influence of different nozzle cooling concepts on thrust, with subsequent cooling air requirements, is investigated. The optimum ratio of exit area/throat area of convergent/divergent nozzles dependent on nozzle concept and nozzle pressure ratio is identified. The performance comparison shows that fully variable convergent/divergent nozzles promise some advantages against the simple convergent nozzle at high nozzle pressure ratios. However, the higher weight and complexity of convergent/divergent nozzles lead to the conclusion that the choice of convergent/divergent nozzles for reheated turbofan engines in combat aircraft is not generally justified.

695. LEVART, P.: **Experimental study of the interaction between the wing of a subsonic aircraft and a nacelle of a high by-pass ratio engine.** NASA-TM-76606 1981. 81N27043

The oncoming of a new generation of subsonic transport aircraft (with supercritical wing and high by-pass ratio turbofans) led to an experimental study of wing nacelle jet pylon interference in transonic flow. To this end, a test set-up was developed at the ONERA S3Ch wind tunnel. The nacelle models represent a turbofan by means of two compressed air jets. The scale is 1/18.5. The nacelles are fixed on a thrust balance measuring afterbody thrust and discharge coefficients. The wing is located between the sidewalls of the test section. Pressures are measured through 456 holes located on 8 airfoils. Drag coefficient of the wing is obtained by wake survey. The following parameters can vary (1) wing/nacelle position; (2) upstream Mach number (from 0.3 to 0.8); (3) jet pressure ratio; (4) with/without pylon and (5) type of nacelle. Wing nacelle interference can be studied by means of total thrust drag analysis as a function of the various parameters. The test set-up is described and examples of results are presented.

696. SMYTH, R.: **Computer programs for the design and performance evaluation of nacelles for high bypass-ratio engines.** In AGARD The Use of Computers as a Design Tool, 21 p (See 80N21243 12-01) 1980. 80N21270

The use of the computer as a design tool for the different stages of nacelle development and integration with the airframe is discussed. Trends in propulsion system development and methods of calculation suitable for computerized work with nacelles are reported. The computer program developed for nacelle synthesis consists of an executive program which uses program modules based on the engine component breakdown. The main program modules are the geometrical requirements, the inlet definition, the nozzle and afterbody definition, and the flow calculation. Each program module and its function in the executive program is discussed. The use of the computer program for the performance evaluation of nacelles during the aircraft design process is described.

697. LEVART, P.: **Experimental study of the interaction between the wing of a subsonic aircraft and a nacelle of a high by-pass ratio engine.** In AGARD Subsonic/ Transonic Configuration Aerodyn., 11 p (See 81N15991 07-02) 1980. 81N16010

The oncoming of a new generation of subsonic transport aircraft (with supercritical wing and high by-pass ratio turbofans) has led to an experimental study of wing nacelle jet pylon interference in transonic flow. To this end, a test set-up was developed at the ONERA S3Ch wind tunnel. The nacelle models represent a turbofan by means of two compressed air jets. The scale is 1/18,5. The nacelles are fixed on a thrust balance measuring afterbody thrust and discharge coefficients. The wing is located between the sidewalls of the test section. Pressures are measured through 456 holes located on 8 airfoils. Drag coefficient of the wing is obtained by wake survey. The following parameters can vary: (1) wing/nacelle position; (2) upstream Mach number (from 0.3 to 0.8); (3) jet pressure ratio; (4) with/without pylon; and (5) type of nacelle. Wing nacelle interference can be studied by means of total thrust drag analysis, as a function of the various parameters. The test set-up is described, and examples of results are presented illustrating the possibilities of this set-up.

698. KUHN, G. D.; MCMILLAN, O. J.; PERKINS, S. C., JR.; PERKINS, E. W.: **Evaluation of methods for prediction of propulsion system drag.** AIAA PAPER 79-1148 AIAA, SAE, and ASME, Joint Propulsion Conference, 15th, Las Vegas, Nev., June 18-20, 1979, AIAA 13 p. 1979. 79A38961

The results of a study directed toward compilation of a theoretical and experimental data base covering inlet/airframe and nozzle afterbody integration are described, with the major emphasis on the evaluation of the adequacy for preliminary design purposes of the data base for afterbody/propulsion system interference effects. Prediction methods that exist for afterbody/ airframe interference effects are evaluated with respect to the requirements of breadth, ease of application and accuracy that are important for preliminary design.

699. RICHEY, G. K.; BOWERS, D. L.; KOSTIN, L. C.; PRICE, E. A., JR. **Wind Tunnel/Flight Test Correlation Program on the B-1 nacelle afterbody/nozzle at transonic conditions.** AIAA PAPER 78-989 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 8 p. 1978. 78A48469

The B-1 Wind Tunnel/Flight Test Correlation Program had the objective to investigate the B-1 propulsion nacelle flow field differences between wind tunnel and flight test and determine the sources of these differences. The wind tunnel and flight tests of the program are discussed and a description is presented of the corresponding nacelle afterbody/nozzle instrumentation. A 0.06 scale B-1 nozzle afterbody model was used as wind tunnel model. Flight data were obtained during the B-1 No. 2 structural test flight development program. The test results obtained in the investigations provide a good data base for the study of the flow characteristics in transonic flow and differences/similarities between wind tunnel and flight for an exhaust nozzle/aftbody system which is closely integrated with the wing and fuselage.

700. RICHEY, G. K.; PETERSEN, M. W.; PRICE, E. A., JR.: **Wind tunnel/flight test correlation program on the B-1 nacelle afterbody/nozzle.**: AIAA PAPER 76-673 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 12th, Palo Alto, Calif., July 26-29, 1976, AIAA 26 p. 76A42419

Results of wind tunnel tests of an instrumented 0.06-scale B-1 full aircraft configuration jet effects model are discussed with particular reference to the afterbody/nozzle region. The objective was to investigate and improve correlation procedures between wind tunnel and flight test data for the flow fields associated with the inlet and nozzle of an integrated configuration with airframe/propulsion interference effects representative of advanced transonic/supersonic aircraft. With pressure instrumentation on the nacelle afterbody/nozzle, wind tunnel data indicate good correlation between the forces on the nacelle derived from pressure-area integration and direct measurement with a metric afterbody/nozzle balance. Investigated areas include the effect of model configuration, nozzle pressure ratio, Reynolds number, strut effects, faired-over versus flow-through nacelle, and simulation of inlet bypass and spillage flow.

701. SARGENT, J.; KOSTIN, L.; GILBERTSON, M.: **B-1 wind tunnel test results of 0.06 scale nozzle/afterbody verification model June 1974 test, AEDC TF-336, volume 3.** AD-B043116L NA-75-157-VOL-3 1976. 80X74127 US GOV AGENCIES

702. SARGENT, J.; KOSTIN, L.; GILBERTSON, M.: **B-1 wind tunnel test results of 0.06 scale nozzle/afterbody verification model June 1974 test, AEDC TF-336, volume 2.** AD-B043115L NA-75-157-VOL-2 1976. 80X74126 US GOV AGENCIES

703. LEONARD, J.; GILBERTSON, M. W.: **B-1 air vehicle 0.06 scale nozzle/afterbody verification model wind test results test number one, (AEDC SF-150) (AEDC TF-285).** AD-B043098L NA-74-51 1974. 80X72552 US GOV AGENCIES

704. ZONARS, D.: **Technological advances in airframe-propulsion integration.** ICAS PAPER 72-18 International Council of the Aeronautical Sciences, Congress, 8th, Amsterdam, Netherlands, Aug. 28-Sept. 2, 1972, 17 p. 1972. 72A41143

F-111A aircraft inlet system and TF-30 engine compatibility is reviewed based on an assessment of time averaged and instantaneous distortion parameters. In addition, recent advances in research on inlet configurations associated with steady-state and dynamic distortions are presented. A complete random data acquisition, editing and processing method is described for accomplishing data analysis as an inlet flow diagnostic tool. Finally, recent afterbody and nozzle research results, which improve the technology base for understanding airframe-nozzle interactions, are reviewed. A basic

aircraft configuration incorporating a common forebody, wing, inlet system and a twin engine installation was utilized during high Reynolds number wind tunnel tests to determine the relative merits of a wide spectrum of afterbody-nozzle geometrical variations.

5.0 INLET-ENGINE INTEGRATION

705. YARNG, JIAHN-BO; GUAN, YAN-SHEN: **Optimal control of supersonic inlet/engine combination.** Journal of Guidance, Control, and Dynamics (ISSN 0731-5090), vol. 11, Mar.-Apr. 1988, p. 137-145. 1988.88A36711

This paper applies the techniques of modern optimal control theory to the design of a control system for a two-input, two-output inlet/engine combination. The mathematical model of the integrated combination is formulated using an idea of flow matching of the inlet and the engine. The control problem is approached as a stochastic linear quadratic regulator problem. The state estimator is designed by a recursive eigenvalue-eigenvector method for a linear time-in-variant state equation.The results of a digital simulation for a NASA 48 cm inlet/J85 engine combination show that this design method is satisfactory.

706. ALDEN, ERIC D.: **Improved engine performance utilizing integrated inlet control.**: Digital Avionics Systems Conference, 7th, Fort Worth, TX, Oct. 13-16, 1986, Proceedings (87A31451 13-01). New York, Institute of Electrical and Electronics Engineers, Inc., 1986, p. 710-717. 87A31541

This paper documents the development of a nonlinear multivariable closed loop control for an integrated model of the F100 gas turbine engine with a mixed compression supersonic inlet. The controller is constructed by using a multivariable transfer function synthesis theory called the Total Synthesis Problem (TSP). The implementation of the transfer function synthesis approach to obtain desired output response performance yields both feed forward and feedback controllers in transfer function form. The controllers are easily modified to obtain new desired output response performance. System performance is gauged by the controller's ability to avoid stall conditions and high levels of inlet distortion while providing excellent closed loop response.

707. BOWERS, D. L.: **Throttle dependent forces: A primer.** AD-A162939 AFWAL-TR-85-3055 1985. 86N23599

An introduction to the broad area of throttle dependent forces for airbreathing aircraft, primarily subsonic to supersonic capable is provided. Basic concepts and examples are presented for subsonic, supersonic and transonic inlet and nozzle applications. Experimental and analytical determination of throttle-dependent forces is discussed, including approaches and potential problems. A final reference section of basic definitions is included for completeness.

708. BHOUCHARD, J. H.; CARLIN, C. M.; TJONNELAND, E.: **Inlet, engine, airframe controls integration development for supercruising aircraft.**: International Symposium on Air Breathing Engines, 6th, Paris, France, June 6-10, 1983, Symposium Papers (83A35801 16-07). New York, American Institute of Aeronautics and Astronautics, 1983, p. 342-356. 83A35842

In connection with a consideration of advanced military aircraft systems, attention is given to research for improving the technology of the design of supersonic cruise aircraft. Syberg et al. (1981) have shown that an analytic design method is now available to accurately predict the flow characteristics of axisymmetric supersonic inlets, including off-design angle of attack operation. On the basis of information regarding the inlet flow characteristics, the control system designer can begin the inlet design and development, before wind tunnel testing has begun. The present investigation is concerned with details and status of inlet control technology. A detailed representation of a supersonic propulsion system is developed. This development demonstrates the feasibility of the selected hybrid computational concept.

709. BANGERT, L. H.; SANTMAN, D. M.; HORIE, G.; MILLER, L. D. : **Some effects of cruise speed and engine matching of supersonic inlet design.** AIAA PAPER 80-1807. American Institute of Aeronautics and Astronautics, Aircraft Systems Meeting, Anaheim, Calif., Aug. 4-6, 1980, 9 p. 80A45734

An analytical study was conducted to determine the impact of flight Mach number on inlet type selection for a supersonic cruise aircraft. External and mixed-compression axisymmetric and two-dimensional inlets were considered. The internal contraction of the mixed-compression inlets was limited to achieve self-starting. At Mach 2.0, the axisymmetric mixed-compression inlet

provided the best aircraft range. At Mach 2.3, the two-dimensional mixed-compression inlet was the most attractive if enough variable geometry were incorporated to minimize spillage during subsonic cruise. Increases in takeoff-to-cruise air flow ratio gave lower aircraft range.

710. WASSERBAUER, J. F.; GERSTENMAIER, W. H.: **Inlet-engine matching for SCAR including application of a bicone variable geometry inlet.** NASA-TM-78955 E-9706 1978. 78N27125

Airflow characteristics of variable cycle engines (VCE) designed for Mach 2.32 can have transonic airflow requirements as high as 1.6 times the cruise airflow. This is a formidable requirement for conventional, high performance, axisymmetric, translating centerbody mixed compression inlets. An alternate inlet is defined, where the second cone of a two cone center body collapses to the initial cone angle to provide a large off-design airflow capability, and incorporates modest centerbody translation to minimize spillage drag. Estimates of transonic spillage drag are competitive with those of conventional translating centerbody inlets. The inlet's cruise performance exhibits very low bleed requirements with good recovery and high angle of attack capability.

711. WASSERBAUER, J. F.; GERSTENMAIER, W. H.: **Inlet-engine matching for SCAR including application of a bicone variable geometry inlet.** AIAA PAPER 78-961 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 22 p. 1978. 78A45096

Airflow characteristics of variable cycle engines (VCE) designed for Mach 2.32 can have transonic airflow requirements as high as 1.6 times the cruise airflow. This is a formidable requirement for conventional, high performance, axisymmetric, translating centerbody mixed compression inlets. An alternate inlet is defined where the second cone of a two cone centerbody collapses to the initial cone angle to provide a large off-design airflow capability, and incorporates modest centerbody translation to minimize spillage drag. Estimates of transonic spillage drag are competitive with those of conventional translating centerbody inlets. The inlet's cruise performance exhibits very low bleed requirements with good recovery and high angle of attack capability.

6.0 INLET-AIRFRAME INTEGRATION

6.1 GENERAL SURVEYS

712. JOHNSON, STUART K.: **Flow field study at engine inlet stations of two high-speed cruise aircraft.** NASA-TP-2861 L-16486 NAS 1.60:2861 1989. 89X10301 DOMESTIC

An experimental and computational investigation was conducted to determine the flow field characteristics at three hypothetical inlet stations on a high-speed configuration. The inlet stations evaluated were located at both free-stream and precompression positions on the configuration. The experimental tests were conducted at Mach numbers of 2.86, 3.5, and 4.0 at a Reynolds number per foot of 2,000,000. The computational investigation of the flow field conditions at the inlet stations was conducted using a full potential computer code.

713. BENSON, THOMAS J.: **CFD application to supersonic/hypersonic inlet airframe integration.** In VKI, Intake Aerodynamics, Volume 2, 62 p (See 89N16748 09-02) 1988. 89N16754

Supersonic external compression inlets are introduced, and the computational fluid dynamics (CFD) codes and tests needed to study flow associated with these inlets are outlined. Normal shock wave turbulent boundary layer interaction is discussed. Boundary layer control is considered. Glancing sidewall shock interaction is treated. The CFD validation of hypersonic inlet configurations is explained. Scramjet inlet modules are shown.

714. PATZ, G.: **Shock waves in adjacent engine inlets.**: ISL-R-104/84 Feb. 1984 85N31068

Shock wave diffraction and propagation in two adjacent inlets is studied to get a general view of the effects on the flow in one open inlet. In a bidimensional test room divided into an inlet closed by a perforated plate and an open inlet, reflection shock waves with variable intensity were generated. The propagation and effects on the flow in the open inlet were studied at Mach numbers ranging from 0.6 to 0.7 to 1.6. Films and streak photographs made with a differential interferometer, and the measured values with a differential laser interferometer show a very weak shock wave in subsonic flow. The shock wave is not observed in supersonic flow. In both cases a perturbation caused by a transverse flow associated with a leading edge

vortex separation of the partition wall between the two intakes is observed.

715. MACE, J.; HANKEY, W. L.: **Review of inlet-airframe integration using Navier-Stokes computational fluid dynamics.** AIAA PAPER 84-0119. American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 11 p. 84A17892

Inlet-airframe integration is an aerodynamic discipline dominated by strong viscous-inviscid flow interactions. Although valid approximations can be made which reduce the complexity of the governing equations, these flow interactions are generally described by the Navier-Stokes equations. Computational Fluid Dynamics (CFD) to solve the Navier-Stokes equations for flows relevant to inlet-airframe integration is emerging as an engineering tool. This paper examines current CFD capabilities to compute aircraft forebody and inlet flows which are described by the Navier-Stokes equations.

716. TINDELL, R.; DELANEY, F.; BALL, R.; HINZ, W.; MEBES, M.: **Level 2 inlet installation program, volume 1.** AD-B083906L AFWAL-TR-83-3077-VOL-1 1983. 84X77996 US GOV AGENCIES

717. TINDELL, R.; DELANEY, F.; BALL, R.; HINZ, W.; MEBES, M.: **Level 2 inlet installation program. Volume 2: Two dimensional program users manual.** AD-B083907L AFWAL-TR-83-3077-VOL-2 1983. 84X77997 US GOV AGENCIES

718. TINDELL, R.; TAMPLIN, G.: **An inlet system installed performance prediction program using simplified modeling.** AIAA PAPER 83-1167. AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 15 p. 83A36256

An accurate and comprehensive inlet analysis methodology is needed to evaluate advanced inlet technology for military aircraft, and to predict the preliminary design level of aircraft installed engine performance. A description is presented of the Level II Inlet Installation Program (IIP) which implements such a methodology. The program was developed to be used primarily for estimating/predicting the performance of a given configuration, and to assess relative merits of inlet systems and subsystems for inlet/engine/airframe integration studies. It was derived by integrating several existing computer programs with some new analytical calculation routines which rely upon correlations of test results with simple theoretical descriptions of aerospace phenomena.

719. WELGE, H. R.: **Methods used at Douglas Aircraft for supersonic inlet design and airframe integration.** In NASA Lewis Research Center Inlet Workshop, p 184-200 (See 86N72197 18-01) 1977. 86N72209

6.2 UNDERWING INLETS

720. SMACKRODT, P.-A.; SCHMITZ, D. M.: **Experimental research on an underbody ramp inlet under supersonic flow conditions.** DGLR PAPER 86-142 IN: Yearbook 1986 I; DGLR, Annual Meeting, Munich, West Germany, Oct. 8-10, 1986, Reports (87A36751 15-01). Bonn, Deutsche Gesellschaft fuer Luft- und Raumfahrt, 1986, p. 303-311. In German. 87A36788

An engine inlet with fixed underbody ramp inlet geometry has been developed for use in light fighter aircraft. The design of the inlet, especially that of the system used to divert the boundary layer, is described using theoretical methods and experimental optimization conducted for a finite number of slanted shocks. Results are given for the main flow throughput and the performance parameters and for the influence that the boundary layer diversion system and the Mach number and angle of attack exert on those parameters.

721. TARUKHIN, V. P.; TARUSHKIN, A. G.: **Investigation of the parameters of a boundary layer before the inlet of a supersonic air intake mounted under the surface of a triangular plate.** TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 13, no. 2, 1982, p. 69-77. In Russian. 83A37533

An experimental study of the parameters of the boundary layer before the inlet plane of a plane under-the-wing air intake was made at Mach numbers of 2-5 and angles of attack of 0-10 deg. Attention is given to the change in the integral characteristics of the boundary layer as a function of angles of attack and the distance between the intake and the plate surface. It is noted that the simplest and most effective way to reduce the adverse effect of the boundary layer on the internal characteristics of the intake is to move the intake away from the wing surface.

722. CAWTHON, J.: **Advanced inlet concepts for high angle of attack operation for a fuselage-shielded inlet configuration.** In NASA Lewis Research Center Inlet Workshop, p 184-200 (See 86N72197 18-01) 1977. 86N72228

6.3 FUSELAGE MOUNTED INLETS

723. SURBER, LEWIS E.: **Intake-airframe integration.** In VKI, Intake Aerodynamics, Volume 1, 66 p (See 89N16738 09-02) 1988. 89N16744

Intake-airframe integration of tactical aircraft is reviewed. It is shown that the stream flow approaching a side-mounted inlet is substantially distorted by the presence of the fuselage in maneuvering flight. This flow distortion has a generally adverse effect on inlet total pressure recovery and inlet-engine compatibility. Supersonic maneuvering flight can lead to substantial performance degradation in a side-mounted leeward 2-D inlet due to flow separation at the inboard sideplate. Performance degradation in side-mounted half-axisymmetric inlets in supersonic maneuvers results from flow separation in the upper portion of the throat followed by choking of the rest of the throat. Flow field studies show dramatic potential performance advantages for shielding supersonic maneuvering inlets. Fuselage-shielding, however, is the only technique which retains all the advantages for 2-D inlets when alpha/Beta combinations were explored. Half-axisymmetric inlets show substantial performance advantages over 2-D inlets in supersonic wing-shielded flow fields when considering the entire maneuver envelope. Experiments demonstrate limited tailoring of top-mounted inlet flow fields through careful design of wing leading-edgestrakes which control the vortex pattern over an aircraft's upper surface. Such designs may be able to facilitate an acceptable inlet environment for limited maneuver conditions.

724. LEYLAND, D. C.: **Intakes for high angle of attack.** In VKI, Intake Aerodynamics, Volume 1, 26 p (See 89N16738 09-02) 1988. 89N16745

Intake design and location for combat aircraft are reviewed. Experience of operation at moderate angles-of-attack was obtained from testing of models of existing aircraft, to the extent of showing what features and characteristics require investigation. Shielding to provide preturning of entry flow is desirable and the chin location chosen for EAP and EFA proves very effective. Research studies, however, included other locations to determine what can be expected and accepted. The chin intake is not always the best overall configuration choice; it constrains fuselage stores carriage in smaller aircraft and is likely to be unacceptable in STOVL aircraft because of hot gas reingestion. Results from research testing, mostly on fuselage integrated intakes, are given to show what flow changes take place with increasing angle-of-attack and what configuration choices can be made to give acceptable characteristics.

725. ADYAK, JOSEPH; SMITH, MARILYN J.; SCHUSTER, DAVID M.: **Navier-Stokes simulations of supersonic fighter intake flow fields.**: AIAA PAPER 87-1752 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 17 p. Research supported by Lockheed Independent Research and Development Programs. 1987 87A45185

An analysis is presented for calculating steady (or unsteady) three-dimensional supersonic fighter intake flow fields. This algorithm can compute the flow field about forebody, inlet, and diffuser configurations at zero or nonzero incidence. The algorithm can solve either the Euler momentum equations for inviscid flow, the thin-and shear-layer Navier-Stokes equations for viscous flow, or the full Navier-Stokes equations for viscous flow. The flow field is determined on a body-fitted numerically-generated computational grid. A fully-implicit alternating-direction-implicit algorithm is employed for solution of the finite-difference equations. Viscous flow results are presented to illustrate application of the analysis for cases at supersonic free-stream speeds.

726. SURBER, L.; SYBERG, J.; KONCSEK, J.: **Performance of highly integrated inlets for supersonic aircraft.** In AGARD Aerodyn. of Power Plant Installation, 12 p (See 82N13065 04-01) 1981. 82N13066

Performance data obtained on several subsonic diffusers applicable to advanced supersonic tactical aircraft configurations were used to select a forebody-inlet model for proof-of-concept wind tunnel performance evaluation. Three of the diffusers were designed for high aspect ratio inlets having throat aspect ratios greater than seven. A fourth design incorporated a low aspect ratio inlet. Two of the high aspect ratio diffusers and the low aspect ratio diffuser incorporated duct bends typical of inlets substantially offset from the engine centerline. Preliminary tests of the high aspect of ratio diffuser produced high total pressure recovery coupled with relatively low flow distortion. Furthermore, the use of longitudinal vanes in one high aspect ratio diffuser

provided reductions in engine face flow distortion with very little performance degradation. Proof-of-concept tests further investigated the performance of a high aspect ratio, side-mounted external compression supersonic inlet. Tests were performed in a 16-foot supersonic propulsion wind tunnel at Mach numbers of 1.6 to 2.2 over a -5 to 12 deg angle of attack range and sideslip angles from -8 to +8 deg. The results of these tests support the use of high aspect ratio inlets with sharp duct bends as a viable design option in future supersonic aircraft designs.

727. SURBER, L. E.: **Effect of forebody shape and shielding technique on 2-D supersonic inlet performance.** AIAA PAPER 75-1183 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 11th, Anaheim, Calif., Sept. 29-Oct. 1, 1975, AIAA 20 p. 1975. 76A10253

Diagnostic data from large-scale airframe-inlet model wind tunnel tests have been analyzed to facilitate understanding of 2-D inlet installations in highly maneuverable supersonic aircraft. Inlet performance levels associated with various forebody shapes and integration techniques (side-mounted, wing-shielded, and fuselage-shielded) are compared to assess airframe interference effects. Examinations of upstream airframe flow fields together with total pressure surveys through the duct and at the compressor face are used to explain trends of total pressure recovery,duct turbulence and compressor face steady-state and dynamic flow distortion index over a wide range of flight maneuver conditions.

728. CAWTHON, J. A.; CROSTHWAIT, E. L.; HILL, P. W.; LOWERY, B. T.; TRUAX, P. P.: **Supersonic inlet design and airframe-inlet integration program (Project Tailor-Mate). Volume 1: Vehicle conceptual design and performance analysis.** AD-910778L AFFDL-TR-71-124-VOL-1 1973. 73X79660 US GOV AGENCIES

729. CAWTHON, J. A.; CROSTHWAIT, E. L.; TRUAX, P. P.: **Supersonic inlet design and airframe-inlet integration program (Project Tailor-Mate). Volume 2: Forebody flow-field investigation.** AD-910779L AFFDL-TR-71-124-VOL-2 1973. 73X79661 US GOV AGENCIES

730. CAWTHON, J. A.; TRUAX, P. P.; STEENKIN, W. G.: **Supersonic inlet design and airframe-inlet integration program, project Tailor-Mate. Volume 3: Composite inlet investigation.** AD-910780L AFFDL-TR-71-124-VOL-3 1973. 73X81798 US GOV AGENCIES

731. DIETZ, W. E.; JR.: **Calculations of viscous flow over 3-dimensional inlet-forebody configurations.** AD-B067016 AEDC-TR-82-5 1982. 83X70191 US GOV AGENCIES

6.4 TOP MOUNTED INLETS

732. WIDING, K.: **Efficiency of a top-mounted inlet system at transonic/supersonic speeds.**: International Council of the Aeronautical Sciences, Congress, 14th, Toulouse, France, September 9-14, 1984, Proceedings. Volume 1 (84A44926 22-01). New York, American Institute of Aeronautics and Astronautics, 1984, p. 465-475. 84A44980

At transonic and supersonic speeds an experimental investigation has been carried out to increase the knowledge of the combined effects of the favorable wing flow and the disturbances from the forebody and especially the canopy on the inlet performance of an aircraft concept characterized by its inlet position on top of the fuselage. Wind tunnel tests were performed with a 1:23.5 model in one of FFA's transonic/ supersonic wind tunnels. At the engine face station steady state pressure measurements were carried out to establish the inlet performance and the canopy was equipped with pressure taps giving the static pressure distribution. Results are presented which show that in many respects the inlet performances are very good but they also indicate some problem areas caused by the complex flow in front of the inlet.

733. SMELTZER, D. B.; NELMS, W. P.; WILLIAMS, T. L.: **Airframe effects on a top-mounted fighter inlet system.** (American Institute of Aeronautics and Astronautics and NASA Ames Research Center, V/STOL Conference, Palo Alto, CA, Dec. 7-9, 1981, AIAA 81-2631.) Journal of Aircraft, vol. 19, Dec. 1982, p. 1083-1087. 83A13166

(Previously cited in issue 07, p. 963, Accession no. 82A19212)

734. WILLIAMS, T. L.; HUNT, B. L.; SMELTZER, D. B.; NELMS, W. P.: **Top-mounted inlet system feasibility for transonic-supersonic fighter aircraft.** NASA-TM-81292 A-8575 1981. 81N24066

The more salient findings are presented of recent top inlet performance evaluations aimed at assessing the feasibility of top-mounted inlet systems for transonic-supersonic fighter aircraft applications. Top inlet flow field and engine-inlet performance test data show the influence of key aircraft configuration variables-inlet longitudinal position, wing leading-edge extension planform area, canopy-dorsal integration, and variable incidence canards-on top inlet performance over the Mach range of 0.6 to 2.0. Top inlet performance data are compared with those or more conventional inlet/airframe integrations in an effort to assess the viability of top-mounted inlet systems relative to conventional inlet installations.

6.5 FOREBODY FLOWS

735. HAYNES, DAVY A.; MILLER, DAVID S.; KLEIN, JOHN R.; LOUIE,CHECK M.: **Design and experimental verification of an equivalent forebody to produce disturbances equivalent to those of a forebody with flowing inlets.** AIAA PAPER 88-0195. AIAA, Aerospace Sciences Meeting, 26th, Reno, NV, Jan. 11-14, 1988. 12 p. 88A22143

A method by which a simple equivalent faired body can be designed to replace a more complex body with flowing inlets has been demonstrated for supersonic flow. An analytically defined, geometrically simple faired inlet forebody has been designed using a linear potential code to generate flow perturbations equivalent to those produced by a much more complex forebody with inlets. An equivalent forebody wind-tunnel model was fabricated and a test was conducted in NASA Langley Research Center's Unitary Plan Wind Tunnel. The test Mach number range was 1.60 to 2.16 for angles of attack of -4 to 16 deg. Test results indicate that, for the purposes considered here, the equivalent forebody simulates the original flow field disturbances to an acceptable degree of accuracy.

736. PAYNTER, G. C.; SALEMANN, V.; STROM, E. E. I.: **Inlet flow field investigation. Part 2: Computation of the flow about a supercruise forebody at supersonic speeds.** NASA-CR-172315 NAS 1.26:172315 D180-27939-2 1984. 84N21516

A numerical procedure which solves the parabolized Navier-Stokes (PNS) equations on a body fitted mesh was used to compute the flow about the forebody of an advanced tactical supercruise fighter configuration in an effort to explore the use of a PNS method for design of supersonic cruise forebody geometries. Forebody flow fields were computed at Mach numbers of 1.5, 2.0, and 2.5, and at angles-of-attack of 0 deg, 4 deg, and 8 deg. at each Mach number. Computed results are presented at several body stations and include contour plots of Mach number, total pressure, upwash angle, sidewash angle and cross-plane velocity. The computational analysis procedure was found reliable for evaluating forebody flow fields of advanced aircraft configurations for flight conditions where the vortex shed from the wing leading edge is not a dominant flow phenomenon. Static pressure distributions and boundary layer profiles on the forebody and wing were surveyed in a wind tunnel test, and the analytical results are compared to the data. The current status of the parabolized flow field code is described along with desirable improvements in the code.

737. YAROS, S. F.: **Theoretical and experimental engine-inlet flow fields for fighter forebodies.** NASA-TP-2270 L-15639 NAS 1.60:2270 1984. 84N17132

The capability of two numerical methods, one for transonic and one for supersonic flows, to predict the flow fields about representative fighter aircraft forebodies in the vicinity of the engine inlets was examined. The Mach number range covered was 0.9 to 2.5 and the angle-of-attack range was 0 deg to 25 deg. The computer programs that implement each of the numerical methods are described as to their features and usage, and results are compared with comprehensive wind tunnel data. Although both prediction methods were inviscid, results show that the aerodynamic effects of the forebody, with and without a wing, can be simulated fairly well. Further work is needed to include the effects of viscosity, including vortex shedding.

738. YAROS, S. F.: **Evaluation of two analytical methods for the prediction of inlet flow fields in the vicinity of generalized forebodies.**: AIAA PAPER 82-0959. American Institute of Aeronautics and Astronautics and American Society of Mechanical Engineers, Joint Thermophysics, Fluids, Plasma and Heat Transfer Conference, 3rd, St. Louis, MO, June 7-11, 1982, AIAA 11 p. 82A31935

An investigation of the capability of two computer programs to simulate transonic and supersonic flows about representative fighter aircraft forebodies has been carried

out for purpose of predicting flow fields in the vicinity of typical inlet locations. Each computer program is described as to its features and usage, and results are compared with comprehensive wind tunnel data. Although both computer codes were inviscid, results show that the gross aerodynamic effects of the forebody, with and without a wing, can be simulated fairly well. Further work is needed to include the effects of viscosity including vortex shedding.

7.0 NOZZLE-AIRFRAME INTEGRATION

7.1 GENERAL SURVEYS

739. BOWERS, D. L.; LAUGHREY, J. A.: **Integration of advanced exhaust nozzles.** In AGARD Aerodyn. of Power Plant Installation, 14 p (See 82N13065 04-01) 1981. 82N13075

Attributes of both axisymmetric and nonaxisymmetric advanced nozzles and their incorporation into an aircraft to improve cruise performance, maneuverability and short takeoff and landing operation are discussed. It was concluded that when used as a trimming device, advanced exhaust nozzles with thrust vectoring can provide significant aircraft cruise drag reduction. The aftbody/nozzle installation for advanced airframes and exhaust nozzles must be approached very carefully to demonstrate an installed drag benefit. For maneuver, advanced thrust vectoring exhaust nozzles show advantages at high angle of attack. Improved turn rate and instantaneous maneuver performance can be provided by utilizing these advanced exhaust nozzles in advanced aircraft. For short takeoff and landing aircraft advanced exhaust nozzles with both thrust vectoring and thrust reversing may be necessary. Thrust vectoring up to 60 degrees (or higher) and a propulsive lift control system may be required.

740. RICHEY, G. K.; BERRIER, B. L.; PALCZA, J. L.: **Two-dimensional nozzle airframe integration technology - An overview.** AIAA PAPER 77-839 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 13th, Orlando, Fla., July 11-13, 1977, AIAA 11 p. 1977. 77A41973

The paper reviews the objectives and some of the accomplishments of a number of programs to develop nonaxisymmetric nozzle technology for future tactical aircraft applications. Specific existing fighter aircraft model tests and preliminary studies are discussed which are designed to generate installed nozzle data, including the effects of thrust vectoring and
reversal.

741. SCHMEER, J. W.: **Exhaust-nozzle - Airframe integration** /U/ 1968. 70X11980 US GOV AGENCIES AND CONTRACTORS

742. BENSON, J. L.; HORIE, G.; MILLER, L. D.: **Theoretical study of engine exhaust nozzle airframe integration** Final report, 27 Jun.1966 - Mar. 1967. LR-20678 AEDC-TR-67-214 AD-822074 1967. 68X10721 US GOV AGENCIES AND CONTRACTORS

7.2 WIND TUNNEL TESTS

743. YETTER, J. A.; EVELYN, G. B.; MERCER, C.: **Transonic wind tunnel test of a supersonic nozzle installation.** AIAA PAPER 82-1045 AIAA, SAE, and ASME, Joint Propulsion Conference, 18th, Cleveland, OH, June 21-23, 1982, AIAA 14 p. 1982. 82A37677

The design of the propulsion system installation affects strongly the total drag and overall performance of an aircraft, and the concept, placement, and integration details of the exhaust nozzle are major considerations in the configuration definition. As part of the NASA Supersonic Cruise Research (SCR) program, a wind tunnel test program has been conducted to investigate exhaust nozzle-airframe interactions at transonic speeds. First phase testing is to establish guidelines for follow-on testing. A summary is provided of the results of first phase testing, taking into account the test approach, the effect of nozzle closure on aircraft aerodynamic characteristics, nozzle installation effects and nacelle interference drag, and an analytical study of the effects of nozzle closure on the aircraft.

744. YETTER, J. A.; EVELYN, G. B.: **Nozzle installation effects for supersonic cruise configurations.** NASA-CR-165835 NAS 1.26:165835 1982. 82X10252 US GOV AGENCIES AND CONTRACTORS

A wind tunnel test was conducted to evaluate exhaust nozzle airframe interactions at transonic speeds, for a

representative supersonic cruise vehicle with an underwing nacelle installation. The purpose of the test was threefold: (1) to establish and validate a test approach from which the nozzle performance, nozzle drag, power sensitive boattail effects, and nozzle airframe interactions could be evaluated; (2) determine the magnitude of the nozzle installation effects for use in related NASA-Supersonic Cruise Technology system studies; and (3) provide a data base for validation of analytical codes. The test results indicated that the test approach does permit evaluation of nozzle airframe interactions and the performance assessment of candidate nozzle concepts for development of low drag supersonic exhaust system installations. Favorable installation effects were found to be significant at high subsonic cruise Mach Numbers. A three dimensional linearized potential flow analysis provided qualitative results that aided in interpretation of the test data.

745. JOHNSON, P.; EVELYN, G.: **Installed nozzle test program.** In its Advan. Concept Studies for Supersonic Vehicles, 18 p (See 82X10002 01-01) 1981. 82X10013
<u>US GOV AGENCIES AND CONTRACTORS</u>

Availability of suitable model hardware, test facilities and current testing practices were reviewed. Previous isolated nozzle test results were studied to determine an appropriate generic supersonic cruise research nozzle design for the installed nozzle test program. A test plan,comprising a summary of the proposed test configurations, test conditions,force bookkeeping techniques, and data reduction requirements was formulated and refined. Nacelle and nozzle model hardware were designed and fabricated. Testing was completed and preliminary analysis initiated. Available computer codes, applicable to the analysis of the test configurations, were surveyed, and a theoretical analysis was initiated. This analysis, made to predict installed nozzle flow field, was limited to assessing the isolated nacelle boattail region. Several simplified representations of the exhaust plume were examined and compared with prior NASA test data.

746. YETTER, J. A.; LEAVITT, L. D.: **Effects of sidewall geometry on the installed performance of nonaxisymmetricconvergent-divergent exhaust nozzles.** NASA-TP-1771 L-13826 1980. 81N15976

The investigation was conducted at static conditions and over a Mach number range from 0.6 to 1.2. Angle of attack was held constant at 0 deg. High pressure air was used to simulate jet exhaust flow at ratios of jet total pressure to free-stream static pressure from 1 (jet off) to approximately 10. Sidewall cutback appears to be a viable way of reducing nozzle weight and cooling requirements without compromising installed performance.

747. WILCOX, F. A.; CHAMBERLIN, R.: **Reynolds number effects on boattail drag of exhaust nozzles from wind tunnel and flight tests.** In AGARD Airframe/Propulsion Interference, 15 p (See 75N23485 15-02) March 1975 75N23506

A family of nacelle mounted high angle boattail nozzles was tested to investigate Reynolds number effects on drag. The nozzles were flown on a modified F-106B and mounted on scale models of an F-106 in a wind tunnel. A 19- to 1-range of Reynolds number was covered as a result of the large size differences between models and by flying over a range of altitude. Inflight the nozzles were mounted behind J-85 turbojet engines. Jet boundary simulators and a powered turbojet engine simulator were used on the wind tunnel models. Data were taken at Mach numbers of 0.6 and 0.9. Boattail drag was found to be affected by Reynolds number. The effect is a complex relationship dependent upon boundary layer thickness and nozzle boattail shape. As Reynolds number was increased from the lowest values obtained with scale models, boattail drag first increased to a maximum at the lowest flight Reynolds number and then decreased.

748. HEAD, V. L.; MIKKELSON, D. C.: **Flight investigation of airframe installation effects on a variable flap ejector nozzle of an underwing engine nacelle at Mach numbers from 0.5 to 1.3.**: NASA-TM-X-2010 E-5467 1970 70N26569

This report contains information on airframes, exhaust nozzles, nacelles, aerodynamic drag, aircraft control, ejectors, engine inlets, control surfaces, installation, wing-fuselage stores, and flaps.

8.0 OVERALL PROPULSION SYSTEM INTEGRATION

8.1 GENERAL SURVEYS

749. ANDERSON, J. THOMAS: **Airframe/propulsion integration of supersonic cruise vehicles.** AIAA PAPER 90-2151 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 26th, Orlando, FL, July 16-18, 1990. 11 p. Research supported by USAF. 90A42047

The process of supersonic propulsion system cross-sectional shape definition involves consideration of engine airflow, cruise angle-of-attack, vehicle integration, vehicle weight and balance, thrust distribution vs Mach number, and internal duct pressures. Attention is presently given to the cases of such an inlet/engine/airframe integration problem for turbojet powerplants matched to either two-dimensional or axisymmetric inlets for a Mach 4.2-cruise, JP-fueled aircraft. The axisymmetric propulsion system is found to yield significant reductions in vehicle gross weight and increases in mission range, relative to the two-dimensional inlet configurations.

750. BUSHNELL, D. M.: **Supersonic aircraft drag reduction.** AIAA PAPER 90-1596 AIAA, Fluid Dynamics, Plasma Dynamics and Lasers Conference, 21st, Seattle, WA, June 18-20, 1990. 25 p. 90A38729

This paper reviews aerodynamic drag reduction for friction, wave and vortex drag associated with supersonic cruise aircraft and suggests approaches and research directions. Suction laminar flow control may also enable improved low-speed, high-lift systems, improved lift-to-drag ratio for subsonic cruise, reduced parasitic viscous drag for favorable interference wave drag reduction approaches, and turbulent skin friction reduction via slot injection. Flow separation control at cruise proffers opportunities for increased leading-edge thrust, increased lift increment from upper surface, increased fuselage lift/camber for wave drag-due-to-lift reduction, improved performance of various favorable interference wave drag reduction schemes, as well as possibly better low-speed, high-lift systems and wing cruise performance.

751. HENDERSON, WILLIAM P.: **Propulsion-airframe integration for commercial and military aircraft.** SAE PAPER 872411 IN: International Pacific Air and Space Technology Conference, Melbourne, Australia, Nov. 13-17, 1987, Proceedings (89A10627 01-01). Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 133-144. 89A10637

A significant level of research is ongoing at NASA's Langley Research Center on integrating the propulsion system with the aircraft. This program has included nacelle/pylon/wing integration for turbofan transports, propeller/nacelle/wing integration for turboprop transports, and nozzle/afterbody/empennage integration for high performance aircraft. The studies included in this paper focus more specifically on pylon shaping and nacelle location studies for turbofan transports, nacelle and wing contouring and propeller location effects for turboprop transports, and nozzle shaping and empennage effects for high performance aircraft. The studies were primarily conducted in NASA Langley's 16-Foot Transonic Tunnel at Mach numbers up to 1.20. Some higher Mach number data obtained at NASA's Lewis Research Center is also included.

752. HENDERSON, W. P.: **Propulsion/airframe integration: An overview** 1986. 86X10199 DOMESTIC

The Propulsion Airframe Integration Activities at the Langley Research Center addressed include: the integration of the nozzles with the afterbody of high-performance fighter type aircraft; the utilization of the nozzles to provide the fighter aircraft with enhanced capability by incorporating thrust vectoring and thrust reversing; the integration of turbofan nacelles with the wing and pylons; and the integration of turboprops in both the wing tractor and fuselage mounted pusher configurations.

753. KUTNEY, J. T.: **Advancements in the aerodynamic integration of engine and airframe systems for subsonic aircraft.** International Journal of Turbo and Jet-Engines, vol. 1, no. 1, 1983-1984, p. 29-43. 1984. 84A31316

A comparative study is conducted for the relative aerodynamic advantages or penalties of subsonic aircraft wing- and fuselage-mounted nacelle installations. Both short duct and long duct nacelles are considered, and theoretical treatments for the phenomenon of interference drag are compared with wind tunnel data which illustrate the importance of such diagnostic test results in the isolation of the integration problem and the reduction of installed drag. Attention is given to parasitic drag component breakdowns for engine core cowl, pylon scrubbing, and plug scrubbing, as well as external friction and pressure drag, together with the phenomena of nacelle-fuselage and nacelle-wing channel flow areas and interference drag.

754. VINT, A.: **Engine-airframe interference effects.** In AGARD Spec. Course on Subsonic/ Transonic Aerodyn. Interference for Aircraft, 21 p (See 84N12072 03-01) July 1983 84N12086

The various types of interference between a turbo-jet or turbo-fan engine and the airframe as applicable to military aircraft are described in detail. Examples of the effects on overall aircraft aerodynamics are given, including, where possible, simple means for their evaluation. It is shown

that the interference may give either significant benefits or penalties and that relatively minor geometric changes can have profound effects. Above all it is shown that the effects of all aspects of engine airframe interference must be known early in the design process so the pitfalls can be avoided or beneficial effects included in the initial aircraft design.

755. KRENZ, G.: **Engine/airframe interference.** In AGARD Spec.Course on Subsonic/Transonic Aerodyn. Interference for Aircraft, 17 p (See 84N12072 03-01) 1983. 84N12085

A short review about typical aircraft representatives with different types of engine housing is given. The reasons why current commercial transport aircraft designed for the transonic flight regime prefer conventional engine locations under the wing are given. On first sight type of configuration rarely changed over the past 25 years. However, the strength of flow interference was increased considerably due to the rapid progress in engine as well as wing technology. On the engine side mainly the enlarged massflow and fan diameter contribute to the stronger interaction,while the wing tends to thicker leading to higher loaded designs with supercritical flow in the transonic flight regime. The increasing effects of wing/engine interference were studied in several transonic wind-tunnels. Results including those of varying engine distances from the transonic wing are presented.

756. HENDERSON, W. P.: **Fluid Dynamics Panel Symposium on Aerodynamics of Power Plant Installation.** AGARD-AR-173 ISBN-92-835-1436-2 AD-A119357 1982. 83N11138

Powerplant installations involve complex flows, strongly influenced by viscous effects and often with important aerodynamic interactions between the airframe and propulsion system. The introduction of vehicle propulsion concepts, and points of emphasis in aircraft and missile design requirements, provide an expanding range of aerodynamic problems which call for both experimental and theoretical study. Aerodynamic problems in powerplant installation are surveyed and work which has improved basic understanding or has enhanced prediction and design methods in this field is reviewed. Powerplant installation effects for both combat and transport aircraft are emphasized.

757. Aerodynamics of Power Plant Installation. AGARD-CP-301 ISBN-92-835-0301-5 AD-A108300 1981. 82N13065

758. KULFAN, R. M.; SIGALLA, A.: **Airframe-propulsion system aerodynamic interference predictions at high transonic Mach numbers including off-design engine airflow effects.** In AGARD Aerodyn. of Power Plant Installation, 23 p (See 82N13065) Sept. 1981 82N13098

The transonic speed regime for airplanes at conditions where inlet spillage takes place is discussed. A wind tunnel test program to evaluate aerodynamic performance penalties associated with propulsion system installation and operation at subsonic through low supersonic speeds was conducted. The accuracy of analytic methods for predicting transonic engine airframe interference effects was assessed. Study variables included Mach number, angle of attack, relative nacelle location, and nacelle mass flow ratio. Results include test theory comparisons of forces as well as induced pressure fields. Prediction capability of induced shockwave strength and locations is assessed. It was found that large interference forces due to engine location and flow spillage occur at transonic speeds, that theory explains these effects; and that theory can predict quantitatively these effects.

759. COE, P. L., JR.; THOMAS, J. D.; HUFFMAN, J. K.; WESTON, R. P.; SCHOONOVER, W. E., JR.; GENTRY, C. L., JR.: **Overview of the Langley subsonic research effort on SCR configuration.** In its Supersonic Cruise Res. 1979, Pt. 1, p 13-33 (See 81N17981 09-01) 1980. 81N17982

Recent advances achieved in the subsonic aerodynamics of low aspect ratio,highly swept wing designs are summarized. The most significant of these advances was the development of leading edge deflection concepts which effectively reduce leading edge flow separation. The improved flow attachment results in substantial improvements in low speed performance, significant delay of longitudinal pitch up, increased trailing edge flap effectiveness, and increased lateral control capability. Various additional theoretical and/or experimental studies are considered which, in conjunction with the leading edge deflection studies, form the basis for future subsonic research effort.

760. ROENSCH, R. L.; PAGE, G. S.: **Analytic development of improved supersonic cruise aircraft based on wind tunnel data.** In NASA Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 205-227 (See 81N17981 09-01) 1980. 81N17989

Data obtained from the MDNASA cooperative wing tunnel program were used to develop empirical corrections to theory. These methods were then used to develop a 2.2M supersonic cruise aircraft configuration with a cruise trimmed maximum L/D of 10.2. The empirical corrections to the theory are reviewed, and the configuration alternatives examined in the development of the configuration are presented. The benefits of designing for

761. MCMILLAN, O. J.; PERKINS, E. W.; KUHN, G. D.; PERKINS, S.C., JR.: **Data base for the prediction of airframe propulsion system interference effects.** NASA-CR-152316 NEAR-TR-187 1979. 81N18045

Supersonic tactical aircraft with highly integrated jet propulsion systems were investigated. Primary attention was given to those interference effects which impact the external aerodynamics of the aircraft.

762. JOHNSON, E. S.: **Advanced technology engine integration/acoustic study.** NASA-CR-159298 MDC-J4601 1978. 80X10128 US GOV AGENCIES AND CONTRACTORS

The integration and evaluation near term and advanced technology low bypass engines and advanced technology variable cycle engines using the MDC 2.2M baseline supersonic airplane is reported. The mission and acoustics performance of the airplane with each engine installed is determined. An analysis of each engine/airplane combination is conducted to determine the effect of the engine on the configuration, weight, strength, mission performance, and resulting noise. Resulting capabilities included ranges up to 4150 n.mi. for the near term low bypass engines, 4800 n.mi. for the intermediate term (1982) low bypass engines, and 4900 n.mi. for the intermediate term advance technology variable cycle engines.

763. WILSON, J. R.; BENSON, J. L.: **Propulsion system airframe integration studies - Advanced supersonic transport.** AIAA PAPER 78-1053 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 7 p. 1978. 78A48488

One of the objectives of the considered integration studies is related to the identification of engine/airframe configurations which offer the best performance potential within environmental constraints. Other objectives include the identification of engine cycle and geometry improvements, the development of practical preliminary designs of most promising configurations, and the identification of test and development program requirements. The variables examined in the study are related to the engine nacelle location, the inlet configuration, the engine cycle/configuration, engine-inlet airflow match, engine thrust schedule, and engine accessory location. Attention is given to propulsion system configurations, tradeoff studies, engine-inlet matching studies, aspects of nacelle design integration, and engine operational procedures.

764. FITZSIMMONS, R. D.; ROWE, W. T.; JOHNSON, E. S.: Advanced supersonic transport engine integration studies for near-term technology readiness date. AIAA PAPER 78-1052 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 8 1978. 78A48487

The identification of the proper engine cycle, or cycles, is the most critical task facing the advanced supersonic technology teams today. It determines research requirements in propulsion, acoustics and aerodynamics plus overall program timing, requirements, funding and, eventually, airline acceptance. This paper compares the results of a near-term engine-airframe integration study covering four U.S. engine company low-bypass-ratio turbojet engine designs that have technology readiness dates from 1978 to 1982 for program go-ahead. The effects of changes in technology readiness dates are described and compared with variable-cycle engines of more advanced technology reported on earlier. In addition, study results of a European engine design with a 1982 technology readiness date are included. A typical low-bypass-ratio engine cycle is chosen to illustrate the effect on airplane performance caused by optimum inlet-engine airflow matching. A new Douglas Aircraft Company baseline airplane designed to carry 225 passengers in an all metal airframe which can be ready for an early- to mid-1980 go-ahead is used for the detailed

765. HARTILL, W. R.; GOEBEL, T. P.; VANCAMP, V. V.: **Study of hypersonic propulsion/airframe integration technology.** NASA-CR-145321 NA-78-24 1978. 78N19096

An assessment is done of current and potential ground facilities, and analysis and flight test techniques for establishing a hypersonic propulsion/airframe integration technology base. A mach 6 cruise prototype aircraft incorporating integrated Scramjet engines was considered

the baseline configuration, and the assessment focused on the aerodynamic and configuration aspects of the integration technology. The study describes the key technology milestones that must be met to permit a decision on development of a prototype vehicle, and defines risk levels for these milestones. Capabilities and limitations of analysis techniques, current and potential ground test facilities, and flight test techniques are described in terms of the milestones and risk levels.

766. WILSON, J. R.; WRIGHT, B. R.: **Airframe engine integration with variable cycle engines.** AIAA PAPER 77-798 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 13th, Orlando, Fla., July 11-13, 1977, AIAA 8 p. 1977. 77A41961

The paper studies the feasibility of using variable cycle engines, which have the ability to operate like turbofans during subsonic cruise and like turbojets at supersonic cruise, to regulate airflow and better match the engine with the inlet and reduce off-design penalties for second generation SST designs employing the over/under concept of engine installation. A study of engine performance penalties related to inlet matching was performed on a advanced SST baseline aircraft with under/over nacelles containing VCE's with two different mixed compression inlet designs: a translating centerbody axisymmetric inlet, and a two-dimensional, articulated centerbody, vertical wedge. Mission analyses show that the variable geometry features of VCE's allow engine airflow to be scheduled to match either type of inlet for minimum installations costs.

767. WELGE, H. R.; RADKEY, R. L.; HENNE, P. A.: **Nacelle aerodynamic design and integration study on a Mach 2.2 supersonic cruise aircraft.** AIAA PAPER 76-757 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 12th, Palo Alto, Calif., July 26-29, 1976, AIAA 12 p. 1976. 76A42436

Results of a propulsion system integration study performed on a Mach 2.2 advanced supersonic cruise aircraft are discussed. Numerous inlet-nacelle combinations were examined in a preliminary screening study. Promising configurations were evaluated in a nacelle installation study in which structural weight and installed wave drag were traded leading to the selection of an axisymmetric single-engine pod installation as the most promising configuration. A detailed nacelle shape study was conducted, and a wing reflex was designed. A wind-tunnel test of the refined nacelle with both mixed and external compression inlets was conducted with the nacelles installed on both a refined baseline wing and a reflexed wing. Good agreement was observed between calculated and experimental increments in induced drag due to nacelle installation.

768. BENSON, J. L.; SEDGWICK, T. A.; WRIGHT, B. R.: **Supersonic cruise vehicle propulsion system integration studies.** AIAA PAPER 76-756 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 12th, Palo Alto, Calif., July 26-29, 1976, AIAA 10 p. 1976. 76A42435

The performance and systems integration aspects of a unique engine installation for a supersonic cruise vehicle, identified during an engine location study, are discussed. This installation consists of four separate engine nacelles - two located under the wing and two located over the wing at the same spanwise positions. This nacelle arrangement, while having some propulsion system performance and weight penalties relative to a more conventional configuration employing four underwing nacelles, offers improved vehicle mission performance because of reduced noise, improved low speed lift characteristics and reduced tail size. Propulsion system performance comparisons, integration studies and noise and mission performance results are presented showing that the over/under engine nacelle arrangement is an attractive supersonic cruise vehicle propulsion system configuration and worthy of additional study.

769. RICHEY, G. K.; SURBER, L. E.; LAUGHREY, J. A.: **Airframe/propulsion system flow field interference and the effect on air intake and exhaust nozzle performance.** In AGARD Airframe/Propulsion Interference 31 p (SEE 75N23485 15-02) 1975. 75N23508

The interference between the airframe flow field and the internal/external flow in the air intakes and exhaust nozzles of high performance tactical aircraft is shown to have a significant impact on the performance and operating characteristics of these components, and hence on overall aircraft performance. The internal flow characteristics of an inlet system closely integrated with the airframe are strongly influenced by flow field nonuniformities generated by the airframe forebody and wing, particularly at the higher angles of attack or yaw which modern tactical aircraft are capable of. Comparisons are made of the inlet ambient (capture plane) flow field, and pressure recovery, steady state and dynamic inlet distortion at the simulated engine compressor face for both integrated (side mounted and

fuselage or wing-shielded) and isolated inlet systems to quantitatively assess the airframe interference effects. For the engine exhaust nozzles of closely integrated propulsion system/airframe configurations, the major influence of the airframe flow field is associated with the alteration of the viscous and inviscid external flow in the nozzle region, and its effect on external aftbody/nozzle drag. A detailed discussion, supported by experimental data, shows the effects on airframe aftbody/nozzle installed performance with respect to twin jet interference, wing flow, aircraft tail/control surfaces, interfairings and free stream flow conditions.

770. WITTMANN, M.: **Investigation of the mutual interference of wing/engine combinations.**: ESA-TT-217 DLR-FB-74-32 Dec. 1975 76N24184

The mutual interference between wing and engine nacelle is significant since aircraft engines are often arranged either above or below the wing. For theoretical calculations the wing is represented by a flat plate and the engine nacelle by a cylinder composed of source and vortex singularities. The normal velocity components induced on the wing by the nacelle are simulated by additional singularities on the wing in order to obtain a first approximation of the modified pressure distribution. Experimental results are represented for nine wing/nacelle combinations and three angles of attack. Three different intake blockages are also considered. For several cases the theoretical and experimental results are compared.

771. BENCZE, D. P.: **Nacelle-airframe interference at low supersonic Mach numbers.** AIAA PAPER 72-1113 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Specialist Conference, 8th, New Orleans, La., Nov. 29-Dec. 1, 1972, AIAA 11 p. 1972. 73A13428

The aerodynamic interference between the propulsion system and airframe for a low supersonic transport with wing-mounted nacelles is examined. Both a flowfield analysis and the equivalent body approach were used to predict the interference lift, drag, and pitching moment as functions of nacelle size, shape, and position. The results indicate that the interference lift and pitching moment, as well as drag, must be included in the analysis to properly assess the interference effects. In addition, the performance of the basic wing was found to play an important role in determining the effectiveness of the interference lift in reducing the net installation drag. Based on a conservative prediction, the interference effects can reduce the installed propulsion system drag to 40% of the isolated drag of the nacelles. Furthermore, including the interference effects in the optimization of the engine cycle from a thermodynamic and weight standpoint can result in a considerable reduction in the net propulsion system weight fraction (fuel plus engines) while increasing the optimum engine bypass ratio of a typical transport vehicle.

772. ZONARS, D.: **Technological advances in airframe-propulsion integration.** ICAS PAPER 72-18 International Council of the Aeronautical Sciences, Congress, 8th, Amsterdam, Netherlands, Aug. 28-Sept. 2, 1972, 17 p. 1972. 72A41143

F-111A aircraft inlet system and TF-30 engine compatibility is reviewed based on an assessment of time averaged and instantaneous distortion parameters. In addition, recent advances in research on inlet configurations associated with steady-state and dynamic distortions are presented. A complete random data acquisition, editing and processing method is described for accomplishing data analysis as an inlet flow diagnostic tool. Finally, recent afterbody and nozzle research results, which improve the technology base for understanding airframe-nozzle interactions, are reviewed. A basic aircraft configuration incorporating a common forebody, wing, inlet system and a twin engine installation was utilized during high Reynolds number wind tunnel tests to determine the relative merits of a wide spectrum of afterbody-nozzle geometrical variations.

773. BAALS, D. D.; HARRIS, R. V., JR.; ROBINS, A. W.: **Aerodynamic design integration of supersonic aircraft.** AIAA PAPER 68-1018 1970. 70A42701

774. BAALS, D. D.; HARRIS, R. V., JR.; ROBINS, A. W.: **Aerodynamic design integration of supersonic aircraft.** AIAA PAPER 68-1018 1968. 68A44923

8.2 COMPUTATIONAL FLUID DYNAMICS

775. NARAYAN, J. R.; KUMAR, A.: **A numerical study of hypersonic propulsion/airframe integration problem.** AIAA PAPER 89-0030 AIAA, Aerospace Sciences Meeting, 27th, Reno, NV, Jan. 9-12, 1989. 10 p. 1989. 89A25026

A numerical analysis procedure useful in the propulsion-airframe integration problem has been established. Flow around a generic hypersonic vehicle forebody is solved

using Parabolized Navier-Stokes equations and Thin Layer Navier-Stokes equations. Forebody cross sectional geometry corresponds to a two-ellipse configuration. Effect of forebody geometry on the flow structure, especially at the engine inlet location, is analyzed.

776. CHEN, A. W.; CURTIN, M. M.; CARLSON, R. B.; TINOCO, E. N.: **TRANAIR applications to engine/airframe integration.** AIAA PAPER 89-2165 IN: AIAA Applied Aerodynamics Conference, 7th, Seattle, WA, July 31-Aug. 2, 1989, Technical Papers (89A47626 21-02). Washington, DC, American Institute of Aeronautics and Astronautics, 1989, p. 53-58. 1989. 89A47632

Transonic flow analyses of the mutual interference between turbofan exhaust flows and airframe induced flow fields are presented. The method of analysis whereby regions of different total pressures and temperatures are modeled in the newly developed version of a full potential code (TRANAIR) is explained. Comparisons of computed results with test data show good agreement.

777. NAIK, DINESH A.: **Innovative pylon concepts for engine-airframe integration for transonic transports.** AIAA PAPER 89-1819 AIAA, Fluid Dynamics, Plasma Dynamics and Lasers Conference, 20th, Buffalo, NY, June 12-14, 1989. 13 p. 89A42049

Pylon cross-sectional geometries that are believed to reduce pylon/wing installation drag are analyzed. The basic design philosophy is to alleviate flow acceleration near the pylon/wing junction by aerodynamic means. This involves reshaping the pylon, particularly on the inboard side. In some instances this is achieved by moving the pylon trailing edge closure aft of the wing trailing edge. A three-dimensional Euler code was used for the analysis. Promising pylon shapes are identified for further investigation.

778. SUIKAT, REINER; FAROKHI, SAEED: **Method to optimize nacelle shape in a supersonic cruise aircraft.** (AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Saint Louis, MO, Sept. 14-16, 1987, AIAA Paper 87-2865) Journal of Aircraft (ISSN 0021-8669), vol. 25, Aug. 1988, p. 717-723. Previously cited in issue 03, p. 286, Accession no. 88A14254. 89A12558

779. BOPPE, CHARLES W.: **Aerodynamic analysis for aircraft with nacelles, pylons, and winglets at transonic speeds.**: NASA-CR-4066 NAS 1.26:4066 April 1987 87N18538

A computational method has been developed to provide an analysis for complex realistic aircraft configurations at transonic speeds. Wing-fuselage configurations with various combinations of pods, pylons, nacelles, and winglets can be analyzed along with simpler shapes such as airfoils, isolated wings, and isolated bodies. The flexibility required for the treatment of such diverse geometries is obtained by using a multiple nested grid approach in the finite-difference relaxation scheme. Aircraft components (and their grid systems) can be added or removed as required. As a result, the computational method can be used in the same manner as a wind tunnel to study high-speed aerodynamic interference effects. The multiple grid approach also provides high boundary point density/cost ratio. High resolution pressure distributions can be obtained. Computed results are correlated with wind tunnel and flight data using four different transport configurations. Experimental/computational component interference effects are included for cases where data are available. The computer code used for these comparisons is described in the appendices.

780. VACHAUSSEE, D. S.: **High speed viscous flow calculations about complex configurations.** NASA-TM-88237 A-86199 NAS 1.15:88237 1986. 86N31827

Applications of the NASA Ames Parabolized Navier-Stokes (PNS) code to a variety of complex generic configurations is presented. The algorithm, boundary conditions, initial conditions, and grid generators are discussed as applied to these configurations. The PNS code was used as the mainline procedure to numerically simulate the viscous supersonic flow over these generic configurations. The turbulence model that was used in this study is the Baldwin-Lomax model. The boundary conditions are the usual viscous no slip at the wall, and a characteristic procedure is used to fit the bowshock wave which is the outermost boundary. An elliptic grid generator is employed to discretize the flow domain. In addition, an equilibrium air capability has been incorporated into the code. It uses the curve fits of Tannehill, et al. The flow regimes vary from a Mach number of 2 up to 25. Both laminar and turbulent flow are considered. Varying angles of attack have also been computed. Configurations vary from simple cone-type bodies to lifting winged bodies, such as the space shuttle or the generic supersonic cruise fighter.

781. CHANDRASEKARAN, B.: **Computation and comparison of the installation effects of compression pylons for a high wing transport**. AIAA PAPER 88-0004 AIAA, Aerospace Sciences Meeting, 26th, Reno, NV, Jan. 11-14, 1988. 15 p. 88A22004

The three-dimensional transonic Euler method with boundary layer interaction is used to study the flow about a transport aircraft equipped with NASA-developed compression pylons. The results show that the present pylons perform well under the installed conditions, reducing the wing/pylon junction velocities and thus reducing the installed loft loss and drag. The predicted theoretical results are found to agree moderately well with experimental wind tunnel results.

782. SUIKAT, REINER; FAROKHI, SAEED: **A method to optimize nacelle shape in a supersonic cruise aircraft.** AIAA PAPER 87-2865 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Saint Louis, MO, Sept. 14-16, 1987. 8 p. 88A14254

A computer program is developed to optimize the shape of a nacelle installed in a supersonic aircraft for minimum drag. The program is also capable of optimizing the wing camber of the same aircraft. As a unique feature, the present code accounts for the aerodynamic forces on the entire airplane, in contrast to previous wing camber optimization codes which included only the wing forces. The program is based on a panel method analysis code by Woodward and the accuracy of the program is checked with the available wind tunnel data on isolated components as well as full configurations. The computed results are in general agreement with the available data. The results of several optimization test runs are presented and show agreement with trends predicted by other researchers based on theoretical and experimental studies. At higher angles of attack,when supersonic vortex lift becomes significant, the analysis code underpredicts the aircraft lift coefficient.

783. MURTHY, S. N. B.; PAYNTER, G. C.: **Numerical methods for engine-airframe integration**. New York, American Institute of Aeronautics and Astronautics, Inc. (Progress in Astronautics and Aeronautics. Volume 102), 1986, 554 p. For individual items see 87A11777 to 87A11781. 1986. 87A11776

Various papers on numerical methods for engine-airframe integration are presented. The individual topics considered include: scientific computing environment for the 1980s, overview of prediction of complex turbulent flows, numerical solutions of the compressible Navier-Stokes equations, elements of computational engine airframe integrations, computational requirements for efficient engine installation, application of CAE and CFD techniques to complete tactical missile design, CFD applications to engine/airframe integration, and application of a second-generation low-order panel methods to powerplant installation studies. Also addressed are: three-dimensional flow analysis of turboprop inlet and nacelle configurations, application of computational methods to the design of large turbofan engine nacelles, comparison of full potential and Euler solution algorithms for aeropropulsive flow field computations, subsonic/transonic, supersonic nozzle flows and nozzle integration, subsonic/transonic prediction capabilities for nozzle/afterbody configurations, three-dimensional viscous design methodology of supersonic inlet systems for advanced technology aircraft, and a user's technology assessment.

784. BOWERS, D. L.; BERDAHL, C. H.: **Utilization of computation and experiment for airframe propulsion integration development**. IN: ICAS, Congress, 15th, London, England, September 7-12, 1986, Proceedings. Volume 2 (86A48976 24-01). New York, American Institute of Aeronautics and Astronautics, Inc., 1986, p. 1295-1304. 1986. 86A49110

Computational and experimental engineers must combine efforts to assure efficient use of both computational and experimental resources during future aircraft development. The objective of this cooperative approach is to develop the best possible integration of the propulsion system into the airframe and thereby reduce the enormous risk of committing limited resources to build an unproven design. While a few excellent examples of the joint application of computation and experiment to propulsion integration can be found, a conscious directed effort will be required to satisfy future design problems. The experiment must be used to assist the computational development and the computation must be used to assist experimental accuracy and efficiency. Other factors which currently block cooperative progress such as a lack of code user friendliness and weak management commitment to computations must also be removed. Both the computationalist and the experimentalist should seek to understand the physics of the propulsion component flowfields. Credible progress toward designing optimum propulsion system integrations with the most efficient use of resources will only be achieved through cooperative efforts between both disciplines.

785. VADYAK, J.; SMITH, M. J.: **Simulation of engine installation flow fields using a three-dimensional Euler/Navier-Stokes algorithm.** AIAA PAPER 86-1537 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 22nd, Huntsville, AL, June 16-18, 1986. 14 p. Research sponsored by the Lockheed Independent Research and Development Program. 86A42699

A computer analysis has been developed for calculating the steady (or unsteady) three-dimensional flowfield for engine installations. This algorithm, called ENS3D, can compute the engine installation flowfield for subsonic, transonic or supersonic free-stream speeds. The algorithm can solve either the Euler equations for inviscid flow, the thin-shear-layer Navier-Stokes equations for viscous flow, or the full Navier-Stokes equations for viscous flow. The flowfield solution is determined on a body-fitted numerically-generated computational grid. A fully-implicit alternating-direction-implicit method is employed for solution of the finite-difference equations. For viscous computations, a two-layer eddy-viscosity turbulence model is used to achieve mathematical closure. For the present application, the algorithm is applied to compute transport engine installation flow fields at subsonic and transonic free-stream speeds.

786. NAKADATE, MASAAKI; NAGASHIMA, HIDEFUMI; YANAGIZAWA, MITSUNORI: **Computation of nacelle interference using boundary element method.** In National Aerospace Lab., Proceedings of the 4th NAL Symposium on Aircraft Computational Aerodynamics, p 107-120 (see 88N13253 05-02) 1986. 88N13267

The aerodynamic interference problem of jet transport aircraft due to the close coupling between nacelle and wing is one of the major concerns of aerodynamic engineers. At the research level, the Navier-Stokes code is beginning to be applied to such a problem. At the engineering level the application of the panel method is more practical. This paper presents the results of applying the Boundary Element Method code to the analysis of nacelle interference of a practical jet transport.

787. SHANKAR, V.; SZEMA, K. Y.: **Nonlinear potential analysis techniques for supersonic aerodynamic design.** NASA-CR-172507 NAS 1.26:172507 1985. 87N17670

A numerical method based on the conservation form of the full potential equation has been applied to the problem of three-dimensional supersonic flows with embedded subsonic regions. The governing equation is cast in a nonorthogonal coordinate system, and the theory of characteristics is used to accurately monitor the type-dependent flow field. A conservative switching scheme is employed to transition from the supersonic marching procedure to a subsonic relaxation algorithm and vice versa. The newly developed computer program can handle arbitrary geometries with fuselage, canard, wing, flow through nacelle, vertical tail and wake components at combined angles of attack and sideslip. Results are obtained for a variety of configurations that include a Langley advanced fighter concept with fuselage centerline nacelle, Rockwell's Advanced Tactical Fighter (ATF) with wing mounted nacelles, and the Shuttle Orbiter configuration. Comparisons with available experiments were good.

788. CHEN, A. W.; TINOCO, E. N.: **PAN AIR applications to aero-propulsion integration.** (AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983, AIAA Paper 83-1368) Journal of Aircraft (ISSN 0021-8669), vol. 21, March 1984, p. 161-167. 84A24101

789. CLARK, D. R.; MASKEW, B.; DVORAK, F. A.: **The application of a second generation low-order panel method - program 'Vsaero' - to powerplant installation studies.**: AIAA PAPER 84-0122 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 10 p. Research supported by the General Electric Co. 84A17895

Results from the application of a second generation low-order panel method to a number of powerplant installations are presented. The method, which retains the advantages of ease of use and low operating cost of earlier panel methods while retaining the aerodynamic modelling rigor of higher-order methods was used to predict the flow in and around typical nacelles and aircraft for a wide range of conditions. The ability of the second generation low-order analysis to calculate internal flows without the leakage problems associated with earlier programs is demonstrated and correlation between calculated and measured surface pressures and flow behavior, including predicting streamlines and locating regions of separated flow, is presented.

790. TINOCO, E. N.; CHEN, A. W.: **Transonic CFD applications to engine/airframe integration.** AIAA PAPER 84-0381 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 10 p. 84A18052

The application of transonic computational methods to the analysis of pylon wing-mounted engine/airframe configurations typical of subsonic transports is presented. The computational methods used include a three-dimensional isolated nacelle code based on a time-dependent Euler formulation; an axisymmetric explicit Navier-Stokes code for exhaust system analysis and plume modeling calibration; and a three-dimensional full-potential finite volume wing-body-strut-nacelle code. Comparisons of experimental and calculated pressure distributions on isolated nacelles and on wing-body-strut-nacelle configurations are presented. The agreement between computed results and test data is shown to be very good both in terms of trends and absolute levels.

791. BARBER, T. J.; PRESZ, W. M., JR.: **Computational requirements for efficient engine installation.** AIAA PAPER 84-0120 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 10 p. 84A17893

The current trend towards larger, faster, and more fuel efficient aircraft has emphasized the importance of proper engine installation on aircraft design. Analytical design and design analysis procedures are required by the engine manufacturer to aid in the design of low drag engine installations. This paper reviews the unique computational requirements for engine/aircraft flowfield analyses, presents the current state of the art of such analyses, and presents a logical approach

792. CENKO, A.: **PAN AIR applications to complex configurations.** (American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 21st, Reno, NV, Jan. 10-13, 1983, AIAA Paper 83-0007) Journal of Aircraft (ISSN 0021-8669), vol. 20, Oct. 1983, p. 887-892. 1983. 83A48221

Previously cited in issue 05, p. 577, Accession no. 83A16459

793. CENKO, A.: **PAN AIR applications to complex configurations.** : AIAA PAPER 83-0007 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 21st, Reno, NV, Jan. 10-13, 1983, 11 p. 1983. 83A16459

Predictions obtained using the PAN AIR computer code are compared with test data for a supersonic tactical aircraft configuration (STAC), the Space Shuttle configuration (SSC), a planar-wing weapon (PWW) store configuration, and a cruciform-fin weapon configuration. The PAN AIR predictions are also compared with predictions obtained from the Woodward code for the STAC and the Boppe code for the SSC, as well as with experimental data on the behavior of the PWW store in the STAC flowfield. A cost-effective option for store trajectories (COST) is described, and an application of the COST procedure is discussed. Results are evaluated for an application of the PAN AIR code to the PWW store in the STAC carriage position. It is shown that PAN AIR provides good correlations with test data for regions where linear theory is valid and yields reasonable estimates of store behavior in complex aircraft flowfields at both subsonic and supersonic speeds.

794. CHEN, A. W.; TINOCO, E. N.: **PAN AIR applications to aero-propulsion integration.** AIAA PAPER 83-1368 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 11 p. 83A36364

Several diverse applications of the PAN AIR system to aeropropulsion problems are presented in order to demonstrate the versatility of the method. These illustrative examples involve the coupling of PAN AIR to a three-dimensional boundary layer analysis for obtaining iterative solutions, and include a study of the internal flow losses through a calibration nozzle, the calculation of surface pressures about an isolated nacelle, and the modeling of exhaust flows.

795. KLEVENHUSEN, K. D.; JAKOB, H.; STRUCK, H.: **Calculation of wing-body-nacelle interference in subsonic and transonic potential flow.** In AGARD Aerodyn. in Power Plant Installation 8 p (SEE 82N13065 04-01) 1981. 82N13095

A calculation method especially for transport aircraft wing design with consideration of wing/body or engine/airframe interference was developed. A hybrid method, consisting of a combination of panel method and finite difference method, is an improvement of a well proved analogy method. The panel method is of higher order using linear source and doublet distributions. The transonic flow region is removed from the entire flow field and the panel method is used for calculating boundary values for the subsequent finite difference method. The finite difference method solves the full potential equation in streamline coordinates.

796. KULFAN, R. M.: **Prediction of nacelle aerodynamic interference effects at low supersonic Mach numbers.** In NASA. Langley Res. Center Supersonic Cruise Res. 1979, Pt. 1 p 171-203 (SEE 81N17981 09-01) 1980. 81N17988

The accuracy of analytical predictions of nacelle aerodynamic interference effects at low supersonic speeds are studied by means of test versus theory comparisons. Comparisons shown include: (1) isolated wing body lift, drag, and pitching moments; (2) isolated nacelle drag and pressure distributions; (3) nacelle interference shock wave patterns and pressure distributions on the wing lower surface; (4) nacelle interference effects on wing body lift, drag, and pitching moments; and (5) total installed nacelle interference effects on lift, drag, and pitching moment. The comparisons also illustrate effects of nacelle location, nacelle spillage, angle of attack, and Mach numbers on the aerodynamic interference. The initial results seem to indicate that the methods can satisfactorily predict lift, drag, pitching moment, and pressure distributions of installed engine nacelles at low supersonic Mach numbers with mass flow ratios from 0.7 to 1.0 for configurations typical of efficient supersonic cruise airplanes.

797. MILLER, D. S.; CARLSON, H. W.; MIDDLETON, W. D.: **A linearized theory method of constrained optimization for supersonic cruise wing design.** In its Proc. of the SCAR Conf., Part 1 p 9-24 (SEE 77N17996 09-01) 1976. 77N17998

A linearized theory wing design and optimization procedure which allows physical realism and practical considerations to be imposed as constraints on the optimum (least drag due to lift) solution is discussed and examples of application are presented. In addition to the usual constraints on lift and pitching moment, constraints are imposed on wing surface ordinates and wing upper surface pressure levels and gradients. The design procedure also provides the capability of including directly in the optimization process the effects of other aircraft components such as a fuselage, canards, and nacelles.

798. MACK, R. J.: **A numerical method for evaluation and utilization of supersonic nacelle-wing interference.** NASA-TN-D-5057 1969. 69N19641

8.3 WIND TUNNEL TESTS

799. LAMB, MILTON; CARLSON, JOHN R.; PENDERGRAFT, ODIS C., JR.: **Integration effects of D-shaped, underwing, aft-mounted, separate-flow, flow-through nacelles on a high-wing transport.** NASA-TM-4018 L-16342 NAS 1.15:4018 1987. 88N10773

An experimental investigation was conducted in the Langley 16-Foot Transonic Tunnel at freestream Mach numbers from 0.70 to 0.82 and angles of attack from -3.0 to 4.0 deg to determine the integration effects of D-shaped, underwing, aft-mounted, separate-flow, flow-through nacelles on a high-wing transonic transport configuration. The results showed that the aft-mounted nacelle/pylon produced an increase in lift over that of the wing-body configuration by pressurizing much of the wing lower surface in front of the pylon. For the D-shaped nacelle, a substantial region of supersonic flow over the wing, aft of the lip of the nacelle, canceled the reduction in drag caused by the increase in pressures ahead of the lip, to increase interference and form drag compared with a similar circular-shaped nacelle. The installed drag of the D=shaped nacelle was essentially the same as that of an aft-mounted circular nacelle from a previous investigation.

800. CARLSON, JOHN R.; LAMB, MILTON: **Integration effects of pylon geometry and rearward mounted nacelles for a high-wing transport.** AIAA PAPER 87-1920 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 11 p. 87A45300

Results of a wind-tunnel study of the effect of pylon cross-sectional shape and tow angle on airplane drag and an aft-mounted nacelle are presented. The 1/24-scale wide-body high-wing transport model was tested in the Langley 16-Foot Transonic Tunnel at free-stream Mach 0.7-0.8 and angles of attack from -3 to 4 degrees. A compression-type pylon is found to have the lowest drag at both Mach 0.7 and 0.8 and to be capable of suppressing the velocities in the inboard region of the pylon-wing junction, reducing the extent of supersonic flow and the probability of flow separation. It is also shown that the D-shaped aft-mounted nacelle has a low interference drag, as do previously tested circular nacelles in the same position.

801. ABEYOUNIS, W. K.; PATTERSON, J. C., JR.: **Effect of underwing aft-mounted nacelles on the longitudinal aerodynamic characteristics of a high-wing transport airplane.** NASA-TP-2447 L-15664 NAS 1.60:2447 1985. 86N20345

As part of a propulsion/airframe integration program, tests were conducted in the Langley 16-Foot Transonic Tunnel to determine the longitudinal aerodynamic effects of installing flow through engine nacelles in the aft underwing position of a high wing transonic transfer airplane. Mixed flow nacelles with circular and D-shaped inlets were tested at free stream Mach numbers from 0.70 to 0.85 and angles of attack from -2.5 deg to 4.0 deg. The aerodynamic effects of installing antishock bodies on the wing and nacelle upper surfaces as a means of attaching and supporting nacelles in an extreme aft position were investigated.

802. CARLSON, J. R.; PENDERGRAFT, O. C., JR.; BARTLETT, G. R.: **Comparison of advanced turboprop installation on swept and unswept supercritical wings at transonic speeds.**: AIAA PAPER 85-1264 AIAA,SAE, ASME, and ASEE, Joint Propulsion Conference, 21st, Monterey, CA, July 8-10, 1985. 7 p. July 1985 85A39686

A series of wind-tunnel investigations were conducted to determine the aerodynamic interference associated with the over wing and under wing installation of a turboprop nacelle on 20 deg swept and unswept supercritical wings. The purpose of the investigations was to increase the understanding of the flow interactions involved with the nacelle turboprop integration and to obtain experimental data for the verification of computational prediction techniques. The models were tested in the Langley 16-Foot Transonic Tunnel at Mach numbers from 0.50 to 0.80 and at angles-of-attack from 0 to 5 deg. In addition, data at several propeller pitch angles and advance ratio settings were obtained. This paper which presents only the results of the over-the-wing nacelle installations shows that wing sweep had considerable influence on the installation interference. Large scale flow separation was observed on the swept wing at M = 0.8. Less severe effects were observed at M = 0.7 on the swept wing and for both M = 0.7 and 0.8 on the unswept wing.

803. REUBUSH, D. E.; BARE, E. A.: **Investigation of a supersonic cruise fighter model flow field.** NASA-TM-86361 L-15884 NAS 1.15:86361 1985. 86N15248

An investigation was conducted in the Langley 16-Foot Transonic Tunnel to survey the flow field around a model of a supersonic cruise fighter configuration. Local values of angle of attack, side flow, Mach number, and total pressure ratio were measured with a single multi-holed probe in three survey areas on a model previously used for nacelle/nozzle integration investigations. The investigation was conducted at Mach numbers of 0.6, 0.9, and 1.2, and at angles of attack from 0 deg to 10 deg. The purpose of the investigation was to provide a base of experimental data with which theoretically determined data can be compared. To that end the data are presented in tables as well as graphically, and a complete description of the model geometry is included as fuselage cross sections and wing span stations. Measured local angles of attack were generally greater than free stream angle of attack above the wing and generally smaller below. There were large spanwise local angle-of-attack and side flow gradients above the wing at the higher free stream angles of attack.

804. CAPONE, F. J.; REUBUSH, D. E.: **Effects of varying podded nacelle-nozzle installations on transonic aeropropulsive characteristics of a supersonic fighter aircraft.** NASA-TP-2120 L-15525 NAS 1.60:2120 1983. 83N26821

The aeropropulsive characteristics of an advanced twin engine fighter designed for supersonic cruise was investigated in the 16 foot Transonic Tunnel. The performance characteristics of advanced nonaxisymmetric nozzles installed in various nacelle locations, the effects of thrust induced forces on overall aircraft aerodynamics, the trim characteristics, and the thrust reverser performance were evaluated. The major model variables included nozzle power setting; nozzle duct aspect ratio; forward, mid, and aft nacelle axial locations; inboard and outboard underwing nacelle locations; and underwing and overwing nacelle locations. Thrust vectoring exhaust nozzle configurations included a wedge nozzle, a two dimensional convergent divergent nozzle, and a single expansion ramp nozzle, each with deflection angles up to 30 deg. In addition to the nonaxisymmetric nozzles, an axisymmetric nozzle installation was also tested. The use of a canard for trim was also assessed.

805. HENDERSON, W. P.; PATTERSON, J. C., JR.: **Propulsion installation characteristics for turbofan transports.**: AIAA PAPER 83-0087 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 21st, Reno, NV, Jan. 10-13, 1983, 12 p. 83A16513

Several investigations have been conducted in the Langley 8-Foot Transonic Pressure Tunnel and the Langley 16-

Foot Transonic Tunnel to investigate propulsion integration characteristics for turbofan transport aircraft. These studies have focused on reducing the interference drag for conventional underwing, overwing, upper surface and wing aft-mounted engine nacelle installations. The experimental data presented in this paper will illustrate the difficulties associated with properly integrating nacelles and pylons with advanced supercritical wings. In addition guidelines for integrating the nacelle/pylons to eliminate adverse interference effects and possibly achieve favorable interference are discussed.

806. PAGE, G. S.; CUNNINGHAM, E. J.; WELGE, H. R.: **Supersonic aerodynamic wind tunnel test results of an advanced 2.2 Mach cruise transport configuration.** NASA-CR-165933 NAS 1.26:165933 MDC-J9408 1982. 82X10251 US GOV AGENCIES AND CONTRACTORS

A wind tunnel test of a McDonnell Douglas Mach 2.2 advanced supersonic transport configuration was conducted in the NASA-Langley 4x4 foot supersonic wind tunnel. The purposes of the test were to verify refined aerodynamic analysis procedures, and to verify the performance of the refined wing design, designated wing W4. Comparisons of experimental data with theoretical estimates show good agreement over the test Mach number range of 1.8 to 2.86 Mach. Performance of the refined W4 wing configuration show a 0.92 improvement in L/D from the previous test configuration, for a trimmed, full scale L/D of 9.75 at 2.2 Mach. The configuration also achieves a favorable nacelle interference for the wing/nacelle integration technique used. The experimental data show the W4wing configuration does not present any lateral-directional stability problems at cruise. Data analysis indicates the W4 wing configuration did not produce the predicted pitching moment increment due to nacelle addition. A further L/D improvement is available by recambering the wing for the measured nacelle pitching moment.

807. VAHL, W. A.: **Experimental determination of flow-interference effects of wing-mounted, two-dimensional, full-capture propulsion nacelles in close proximity to a vehicle body at a Mach number of 6.**: NASA-TM-83287 L-15209 NAS 1.15:83287 May 1982 82N25217

Experimental tests have been conducted to determine possible aerodynamic interference effects due to the lateral positioning of two dimensional propulsion nacelles mounted on a wing surface in close proximity to a vehicle body. The tests were conducted at a Mach number of 6 and a Reynolds number 7 million per foot. The angle of attack range for force tests was -9 deg to 9 deg. The model configurations consisted of combinations of rectangular and trapezoidal cross section bodies with a wing swept 65 and a rectangular planform wing. A pair of two dimensional, flow through propulsion nacelles simulated full capture inlet operation.

808. VANENGELEN, J. A. J.; MUNNIKSMA, B.; ELSENAAR, A.: **Evaluation of an experimental technique to investigate the effects of the engine position on engine/pylon/wing interference.**: NLR-MP-81020-U April 1981 82N28262

Free flow and blown nacelle wind tunnel testing of engine-airframe integration are compared, and the magnitude of the parasitic interference of an additional strut and engine inlet fairing is examined. A semispan model, typical of a transport aircraft with a supercritical wing was tested. A 3/4 fan cowl high bypass engine was located at six positions underneath the wing. Measurements included pressure and balance force. It is shown that while accurate simulation of engine nozzle geometry is of prime importance, tests on free flow nacelles are useful for selecting engine position. Interference forces derived from pressure integration are only useful for determining trends in interference effects for flexible initial tests.

809. EWALD, B.; SMYTH, R.: **The role and implementation of different nacelle/engine simulation concepts for wind-tunnel testing in research and development work on transport aircraft.** In AGARD Aerodyn. of Power Plant Installation, 35 p (See 82N13065 04-01) 1981. 82N13086

Different experimental methods and their specific roles in various stages of research and development were investigated. The main problem is the simulation and calibration of the propulsion system. Different simulation methods are: flow through nacelles, powered nacelles (blowing, turbine powered simulators (TPS), ejector powered), inlet models. The TPS represent the most advanced simulation of the high bypass ratio engine in model scale. A large part of the wind tunnel tests still have to rely upon flow through nacelles. A novel flow through nacelle with a variable plug is presented. It is shown that the combination of flow through nacelles and TPS can be efficiently used in the wind tunnel investigation of propulsion system effects for transport aircraft.

810. VANENGELEN, J. A. J.; MUNNIKSMA, B.; ELSENAAR, A.: **Evaluation of an experimental technique to investigate the effects of the engine position on engine/pylon/wing interference.** In AGARD Aerodyn. of Power Plant Installation, 13 p (See 82N13065 04-01) 1981. 82N13090

A flexible experimental technique to study the effect of a variation of engine position for a range of test conditions was evaluated. In this test an underwing mounted 3/4 fan cowl engine was investigated at six different positions as a free flow nacelle and as a strut mounted blown nacelle. Pressure and balance force measurements were made. Some typical aspects of the aerodynamic interference are discussed, notably the value of free flow nacelle measurements. Also a comparison of balance weighed and integrated pressure forces is presented. Results indicate that accurate simulation of the engine nozzle geometry is of prime importance for an investigation concerning engine/airframe integration. Nevertheless, tests on a free flow nacelle may still be useful for the selection of the most favorable engine position. A reasonable correlation was established between interference forces as obtained from pressure integration and balance measurements. However, the pressure forces tend to underestimate the balance forces. For a flexible pathfinder test, interference forces derived from pressure integration only appear to be very useful for the determination of trends in interference effects.

811. LEVART, P.: **Experimental study of the interaction between the wing of a subsonic aircraft and a nacelle of a high by-pass ratio engine.** NASA-TM-76606 1981. 81N27043

The oncoming of a new generation of subsonic transport aircraft (with supercritical wing and high by-pass ratio turbofans) led to an experimental study of wing nacelle jet pylon interference in transonic flow. To this end, a test set-up was developed at the ONERA S3Ch wind tunnel. The nacelle models represent a turbofan by means of two compressed air jets. The scale is 1/18.5. The nacelles are fixed on a thrust balance measuring afterbody thrust and discharge coefficients. The wing is located between the sidewalls of the test section. Pressures are measured through 456 holes located on 8 airfoils. Drag coefficient of the wing is obtained by wake survey. The following parameters can vary (1) wing/nacelle position; (2) upstream Mach number (from 0.3 to 0.8); (3) jet pressure ratio; (4) with/without pylon and (5) type of nacelle. Wing nacelle interference can be studied by means of total thrust drag analysis as a function of the various parameters. The test set-up is described and examples of results are presented.

812. KULFAN, R. M.; SIGALLA, A.: **Airframe-propulsion system aerodynamic interference predictions at high transonic Mach numbers including off-design engine airflow effects.** In AGARD Aerodyn. of Power Plant Installation 23 p (SEE 82N13065 04-01) 1981. 82N13098

The transonic speed regime for airplanes at conditions where inlet spillage takes place is discussed. A wind tunnel test program to evaluate aerodynamic performance penalties associated with propulsion system installation and operation at subsonic through low supersonic speeds was conducted. The accuracy of analytic methods for predicting transonic engine airframe interference effects was assessed. Study variables included Mach number, angle of attack, relative nacelle location, and nacelle mass flow ratio. Results include test theory comparisons of forces as well as induced pressure fields. Prediction capability of induced shock wave strength and locations is assessed. It was found that large interference forces due to engine location and flow spillage occur at transonic speeds, that theory explains these effects; and that theory can predict quantitatively these effects.

813. LEVART, P.: **Experimental study of the interaction between the wing of a subsonic aircraft and a nacelle of a high by-pass ratio engine.** In AGARD Subsonic/ Transonic Configuration Aerodyn., 11 p (See 81N15991 07-02) 1980. 81N16010

The oncoming of a new generation of subsonic transport aircraft (with supercritical wing and high by-pass ratio turbofans) has led to an experimental study of wing nacelle jet pylon interference in transonic flow. To this end, a test set-up was developed at the ONERA S3Ch wind tunnel. The nacelle models represent a turbofan by means of two compressed air jets. The scale is 1/18,5. The nacelles are fixed on a thrust balance measuring afterbody thrust and discharge coefficients. The wing is located between the sidewalls of the test section. Pressures are measured through 456 holes located on 8 airfoils. Drag coefficient of the wing is obtained by wake survey. The following parameters can vary: (1) wing/nacelle position; (2) upstream Mach number (from 0.3 to 0.8); (3) jet pressure ratio; (4) with/without pylon; and (5) type of nacelle. Wing nacelle interference can be studied by means of total thrust drag analysis, as a function of the various parameters. The test set-up is described, and examples of results are presented illustrating the possibilities of this set-up.

814. FLECHNER, S. G.: **Preliminary wind-tunnel investigation of the effects of engine nacelles on a transport configuration with high lift/drag ratios to a Mach number of 1.00.** NASA-TM-82312 LWP-939 71/02/16 81N19099

Wind tunnel tests to determine the effect of engine nacelles added to a low wing fuselage vertical tail configuration utilizing the NASA supercritical airfoil and a refined area ruled fuselage are discussed. The engine arrangement consisted of two aft fuselage, side mounted flow through nacelles and a solid body of revolution mounted above the fuselage in a manner similar to the Boeing 727. A preliminary analysis of the wind tunnel data shows that favorable interference drag can be obtained with the proper longitudinal locations of the nacelles, by canting the nacelle inlets, and by cusping the rearward region of the nacelle.

815. MERCER, C. E.; CARSON, G. T., JR.: **Transonic aerodynamic characteristics of a supersonic cruise aircraft research model with the engines suspended above the wing.** NASA-TM-80145 L-12811 1979. 80N12997

The influence of upper-surface nacelle exhaust flow on the aerodynamic characteristics of a supersonic cruise aircraft research configuration was investigated in a 16 foot transonic tunnel over a range of Mach numbers from 0.60 to 1.20. The arrow-wing transport configuration with engines suspended over the wing was tested at angles of attack from -4 deg to 6 deg and jet total pressure ratios from 1 to approximately 13. Wing-tip leading edge flap deflections of -10 deg to 10 deg were tested with the wing-body configuration. Various nacelle locations (chordwise, spanwise, and vertical) were tested over the ranges of Mach numbers, angles of attack, and jet total-pressure ratios. The results show that reflecting the wing-tip leading edge flap from 0 deg to -10 deg increased the maximum lift-drag ratio by 1.0 at subsonic speeds. Jet exhaust interference effects were negligible.

816. WALKLEY, K. B.: **A comparison of the theoretical aerodynamic characteristics of the .015 scale Douglas Mach 2.2 advanced supersonic cruise transport model with wind tunnel data.** NASA-CR-158897 1978. 80X10001 <u>US GOV AGENCIES AND CONTRACTORS</u>

The theoretical aerodynamic characteristics of the .015 scale Douglas advanced supersonic cruise transport model at Mach numbers from 0.5 to 2.4are presented. Comparisons of these results with measured wind tunnel data are also presented. Aerodynamic data presented include lift, drag, and pitching moment coefficients as well as lift-to-drag ratio characteristics. Both wing-body and wing-body-nacelle configurations were analyzed. The aerodynamic methods employed in the analysis are discussed.

817. BROWN, R. H.: **Integration of a variable cycle engine concept in a supersonic cruise aircraft.** AIAA PAPER 78-1049 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 7 p.. 1978. 78A43574

General Electric Company conducted NASA funded studies to evaluate many different supersonic cruise propulsion concepts and cycle studies for potential application in an advanced supersonic cruise aircraft. Engine concepts were refined to match the in-house study of aircraft characteristics, and data were provided to the aircraft companies for evaluation. Over a two year period, close integration with the aircraft companies improved matching of engine and airplane designs and resulted in a major improvement in aircraft range over that with the original engine offerings. This paper reviews the integration effort and shows the system improvements that did result for one variable cycle engine concept.

818. BENCZE, D. P.: **Experimental evaluation of nacelle-airframe interference forces and pressures at Mach numbers of 0.9 to 1.4.** NASA-TM-X-3321 A-6344 1977. 77N20028

Detailed interference force-and-pressure data were obtained on a representative supersonic transport wing-body-nacelle combination at Mach numbers of 0.9 to 1.4. The basic model consisted of a delta wing-body aerodynamic model with a length of 158.0 cm (62.2 in.) and a wingspan of 103.6 cm (40.8 in.) and four independently supported nacelles positioned beneath the model. The experimental program was conducted in the Ames 11- by 11-Foot Wind Tunnel at a constant unit Reynolds number. The primary variables examined included Mach number, angle of attack, nacelle position, and nacelle mass-flow ratio. Under the most favorable conditions, the net interference drag was equal to 50 percent the drag of four isolated nacelles at M = 1.4, 75 percent at M = 1.15, and 144 percent at M = 0.90. The overall interference effects were found to be rather constant over the operating angle-of-attack range of the configuration. The effects of mass-flow ratio on the interference pressure distributions were limited to the lip region of the nacelle and the local wing surface in the

immediate vicinity of the nacelle lip. The net change in the measured interference forces resulting from variations in the nacelle mass-flow ratio were found to be quite small.

819. BENCZE, D. P.: **Wind tunnel investigation of nacelle-airframe interference at Mach numbers of 0.9 to 1.4 - pressure data, volume 1.** NASA-TM-X-73149 A-4982-VOL-1 1976. 76N26146

Detailed interference force and pressure data were obtained on a representative wing-body nacelle combination at Mach numbers of 0.9 to 1.4. The model consisted of a delta wing-body aerodynamic force model with four independently supported nacelles located beneath the wing-body combination. The model was mounted on a six component force balance, and the left hand wing was pressure instrumented. Each of the two right hand nacelles was mounted on a six component force balance housed in the thickness of the nacelle, while each of the left hand nacelles was pressure instrumented. The primary variables examined included Mach number, angle of attack, nacelle position, and nacelle mass flow ratio. Nacelle axial location, relative to both the wing-body combination and to each other, was the most important variable in determining the net interference among the components.

820. BENCZE, D. P.: **Wind tunnel investigation of Nacelle-Airframe interference at Mach numbers of 0.9 to 1.4-pressure data,volume 2.** NASA-TM-X-73088 A-4982 1976. 76N25144

Detailed interference force and pressure data were obtained on a representative wing-body nacelle combination at Mach numbers of 0.9 to 1.4. The model consisted of a delta wing-body aerodynamic force model with four independently supported nacelles located beneath the wing-body
combination. The primary variables examined included Mach number, angle of attack, nacelle position, and nacelle mass flow ratio. Four different configurations were tested to identify various interference forces and pressures on each component; these included tests of the isolated nacelle,the isolated wing-body combination, the four nacelles as a unit, and the total wing-body-nacelle combination. Nacelle axial location, relative to both the wing-body combination and to each other, was the most important variable in determining the net interference among the components. The overall interference effects were found to be essentially constant over the operating angle-of-attack range of the configuration, and nearly independent of nacelle mass flow ratio.

821. BENCZE, D. P.: **Wind tunnel investigation of Nacelle-Airframe interference at Mach numbers of 0.9 to 1.4-force data.** NASA-TM-X-62489 A-4982 1976. 76N25143

Detailed interference force and pressure data were obtained on a representative wing-body-nacelle combination at Mach numbers of 0.9 to 1.4. The model consisted of a delta wing-body aerodynamic force model with four independently supported nacelles located beneath the wing-body
combination. The model was mounted on a six-component force balance, and the left-hand wing was pressure-instrumented. Each of the two right-hand nacelles was mounted on a six-component force balance housed in the thickness of the nacelle, while each of the left-hand nacelles was pressure-instrumented. The primary variables examined included Mach number, angle of attack, nacelle position, and nacelle mass-flow ratio. Four different configurations were tested to identify various interference forces and pressures on each component; these included tests of the isolated nacelle, the isolated wing-body combination, the four nacelles as a unit, and the total wing-body-nacelle combination. Nacelle axial location, relative to both the wing-body combination and to each other, was the most important variable in determining the net interference among the components.

822. MIKKELSON, D.: **Propulsion airframe integration.** In Kansas Univ. Proc. of the NASA, Ind., Univ., Gen. Aviation Drag Reduction Workshop, p 387-402 (See 76N10997 02-01) 1975. 76N11026

Wind tunnel simulation tests are reported that utilize a 20 inch powered nacelle for airframe integration studies. Considered are: effects of boattail positioning, nacelle size, aft fuselage drag, over-the-wing half span model installation, and turboprop and ducted fan configurations.

823. MUNNIKSMA, B.; JAARSMA, F.: Jet interference of a podded engine installation at cruise conditions. In AGARD Airframe/Propulsion Interference 16 p (SEE 75N23485 15-02). 1975. 75N23490

The results of an experimental wind tunnel test program on the wing-pylon-bypass engine combination of the Airbus A 300 B airplane are presented. Only aerodynamic interference due to the engine jet was considered. For determining the interference drag due to the engine jet as well as to have the possibility to extrapolate the test results from model reference conditions to full scale a test scheme was developed. To prove the validity of the assumptions of this scheme several intermediate steps

were made. As the engine jet-airframe interference is mutual, also effects of the external flow on the internal engine nozzle flow causing engine shifting has to be considered. In order to estimate the magnitude of this influence of the external flow field a two-dimensional model of the fan nozzle has been tested using an optical technique. From these tests the specific features of the fan nozzle flow field ranging from subcritical via supercritical to choked conditions are described.

824. BENCZE, D. P.: **Nacelle-airframe interference at low supersonic Mach numbers.**: AIAA PAPER 72-1113 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Specialist Conference, 8th, New Orleans, La., Nov. 29-Dec. 1, 1972, AIAA 11 p. 73A13428

The aerodynamic interference between the propulsion system and airframe for a low supersonic transport with wing-mounted nacelles is examined. Both a flowfield analysis and the equivalent body approach were used to predict the interference lift, drag, and pitching moment as functions of nacelle size, shape, and position. The results indicate that the interference lift and pitching moment, as well as drag, must be included in the analysis to properly assess the interference effects. In addition, the performance of the basic wing was found to play an important role in determining the effectiveness of the interference lift in reducing the net installation drag. Based on a conservative prediction, the interference effects can reduce the installed propulsion system drag to 40% of the isolated drag of the nacelles. Furthermore, including the interference effects in the optimization of the engine cycle from a thermodynamic and weight standpoint can result in a considerable reduction in the net propulsion system weight fraction (fuel plus engines) while increasing the optimum engine bypass ratio of a typical transport vehicle.

825. JOHNSON, D. F.; MITCHELL, G. A.: **Experimental investigation of the interaction of a nacelle-mounted supersonic propulsion system with a wing boundary layer.** NASA-TM-X-2184 E-59831971. 71N19853

8.4 PERFORMANCE CALCULATIONS

826. MIDDLETON, W. D.: **Aerodynamic design and analysis of supersonic aircraft.** LAR-12857 1990. 91M10422

This integrated system of computer programs has been developed for the aerodynamic design and analysis of supersonic aircraft configurations. The system consists of an executive driver and eight basic computer programs, which are used to build up the force coefficients of a selected configuration. The system employs modified linearized theory methods for the calculation of surface pressures and supersonic area rule concepts, in combination with linearized theory, for the calculation of aerodynamic force coefficients. The goal in developing this integrated system was to develop an easy-to-use supersonic design and analysis capability, with recognition of the need for constraints on linear theory methods to provide physical realism, and with consideration for increased design control over the optimization cycles. Within the system, the executive driver invokes individual modules to provide the data and computations required for configuration design or analysis. In one module, skin friction is computed using turbulent flat plate theory. Wave drag is calculated in either the far-field (supersonic area rule) module or the near-field (surface pressure integration) module. The far-field module is used for wave drag coefficient calculations and for fuselage optimization according to area rule concepts. The near-field module is used primarily as an analysis tool, where detailed pressure distributions are of interest. Lifting pressures, drag-due-to-lift, pitching moment, and trim drag are computed by the lift analysis module, which divides the components of the configuration into a mosaic of "Mach-box" rectilinear elements which are employed in obtaining linear theory solutions. A complementary wing design and optimization module computes the wing shape required to support an optimized pressure distribution at a specified flight condition. A geometry module handles configuration geometry for the system. The user prepares only "drawing-type" geometry data; all "paneling" of the configuration for theoretical analyses is handled by the system. The system was designed to require a minimum of user-prepared input data. The wing pressure module summarizes and tabulates for output the wing surface pressure data for user-specified conditions. A plot module draws configuration pictures according to user-specified size and view parameters. This system is written in FORTRAN IV for batch execution and has been implemented on a CDC CYBER 175 with an overlayed central memory requirement of approximately 62K (octal) of 60 bit words. Plotted output is generated for a CALCOMP plotting system. This program was developed in 1980.

827. MIDDLETON, W. D.: **AERODYNAMIC DESIGN AND ANALYSIS OF SUPERSONIC AIRCRAFT.** LAR-12237 1991. 91M10355

This package is an integrated system of computer programs developed for the design and analysis of supersonic configurations. The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients. The goal of the integrated system is to provide an easily used supersonic design and analysis capability, with recognition of the need for constraints on linear theory methods to provide physical realism. This package should prove useful in the design and analysis of any type of supersonic configuration. The integrated system consists of an executive "driver" and seven basic computer programs, including a geometry input module. The individual modules provide data for configuration design or analysis. Skin friction is computed using turbulent flat plate theory. Wave drag is calculated from either far-field (supersonic area rule) or near-field (surface pressure integration) methods. The far-field method is used for wave drag coefficient calculations and for fuselage optimization according to area rule concepts. The near-field is used primarily as an analysis tool, where detailed pressure distributions are of interest. Lifting pressure, drag due to lift, pitching moment, and trim drag are computed from the lift analysis program which breaks arbitrary wing/fuselage/canard/nacelles/horizontal tail configurations into a mosaic of "Mach-box" rectilinear elements, which are employed in linear theory solutions. A complementary wing design and optimization program solves for the wing shape required to support an optimized pressure distribution at a specified flight condition. A geometry module handles all configuration geometry for the system. All "paneling" of configuration for theoretical analyses is accomplished within the programs, and the user prepares only "drawing-type" geometry specifications for input. A plot module draws configuration pictures according to size and view request. Thus the basis of the system is supersonic linearized theory, modified with the "Whitham" correction to disturbance positioning being used in the propagation of body pressure fields, an optional limiting pressure feature to control the permissible level of upper surface pressure coefficient, and a constraint to limit the upper surface streamwise pressure gradient. The entire design and analysis system is a single overlaid program. The executive level of the system controls module execution by means of special identification cards in the input data. Transfer of data in the system between modules is handled by disk storage and common blocks. The system was developed with an interactive graphics capability, but this ability was developed specific to the NASA Langley Research Center CRT display system and its associated software. This part of the system is considered inoperative in the distributed code because of the lack of supporting software. A user may be able to revive the interactive graphics segment if they already have existing interactive graphics capabilities. The program also provides off-line plotting abilities that require a Calcomp plotter. The Langley Research Center graphic library routines are provided in relocatable form as a plot library. This program is written in FORTRAN and has been implemented on the CDC 6000 series computer with a central memory requirement of approximately 54K (octal) of 60 bit words. This program was developed in 1976.

828. DILLENIUS, M. F.: **Aerodynamic interference between lifting surfaces and lift and cruise fans.** ARC-10833 90M10010

This is a system of three computer programs developed to predict aerodynamic interference in transport-type aircraft. The cases considered are interference between a high-bypass-ratio turbofan engine and a wing-pylon-tail configuration and interference between a fuselage-mounted lift fan and a wing-tail configuration. The methods are applicable to all speeds up to the critical speed of the configuration. The first program calculates the singularity distributions representing the flow model of a high-bypass-ratio turbofan engine and computes the velocity field induced by the singularities. The second program computes the singularity distributions representing the wake of a lift fan exhausting in a crossflow. The path of the jet is predicted and the velocity field induced by the jet is computed. The third program is a vortex lattice lifting surface method which can accommodate a wing with a single pylon per panel and a horizontal tail surface. This program can accept externally induced velocities such as those obtained from the turbo-fan engine program or the lift-fan program. The information obtained from the program is the detailed loading distributions on the wing, pylon, and tail at any angle of attack. The gross lift and pitching moment coefficients are computed. This program has been implemented on the IBM 7094.

829. KNUDSEN, A. W.: **Advanced supersonic transport nacelle installation drag increment.** LEW-12786 1990 90M10580

This program was developed to determine nacelle incremental drag for the NASA arrow-wing configuration of an advanced supersonic transport. It has been recognized that one of the more sensitive problems in the design of a successful supersonic cruising aircraft is that of airframe/engine integration. Recent studies have shown

that drag, weight, and wing camber plane warping are very sensitive to nacelle size and shape. It is important that the engine designer be aware of this sensitivity to engine geometry. Some engine geometry control can be achieved by the designer with no penalty in engine performance, although on a total system basis, some engine performance degradation may be accepted in trade for reduced drag. This program should prove useful by providing a rapid approximate methodology for comparing alternative propulsion system designs for supersonic transports. This program uses a table look-up and interpolation procedure to determine the nacelle incremental drag. Wave drag is represented as a function of free stream Mach number and six independent variables, each a function of nacelle shape and size. Friction drag is defined by four independent variables, each a function of engine geometry. These independent variables are used to determine drag values using a table of existing drag data points. For drag values not directly available, the program interpolates, or extrapolates, among the available table values. The program determines a set of data points for use when calculating the drag associated with a given set of values of the independent variables. Once these data points are found, a cubic equation is fitted and the drag increments are determined. This program is written in FORTRAN IV for batch execution and has been implemented on an IBM 370 series computer with a central memory requirement of approximately 40K of 8 bit bytes. This program was developed in 1976.

830. MIDDLETON, W. D.: **Aerodynamic design and analysis of supersonic aircraft.** LAR-12237 90M10337

This package is an integrated system of computer programs developed for the design and analysis of supersonic configurations. The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients. The goal of the integrated system is to provide an easily used supersonic design and analysis capability, with recognition of the need for constraints on linear theory methods to provide physical realism. This package should prove useful in the design and analysis of any type of supersonic configuration. The integrated system consists of an executive "driver" and seven basic computer programs, including a geometry input module. The individual modules provide data for configuration design or analysis. Skin friction is computed using turbulent flat plate theory. Wave drag is calculated from either far-field (supersonic area rule) or near-field (surface pressure integration) methods. The far-field method is used for wave drag coefficient calculations and for fuselage optimization according to area rule concepts. The near-field is used primarily as an analysis tool, where detailed pressure distributions are of interest. Lifting pressure, drag due to lift, pitching moment, and trim drag are computed from the lift analysis program which breaks arbitrary wing/ fuselage/ canard/ nacelles/ horizontal tail configurations into a mosaic of "Mach-box" rectilinear elements, which are employed in linear theory solutions. A complementary wing design and optimization program solves for the wing shape required to support an optimized pressure distribution at a specified flight condition. A geometry module handles all configuration geometry for the system. All "paneling" of configuration for theoretical analyses is accomplished within the programs, and the user prepares only "drawing-type" geometry specifications for input. A plot module draws configuration pictures according to size and view request. Thus the basis of the system is supersonic linearized theory, modified with the "Whitham" correction to disturbance positioning being used in the propagation of body pressure fields, an optional limiting pressure feature to control the permissible level of upper surface pressure coefficient, and a constraint to limit the upper surface streamwise pressure gradient. The entire design and analysis system is a single overlaid program. The executive level of the system controls module execution by means of special identification cards in the input data. Transfer of data in the system between modules is handled by disk storage and common blocks. The system was developed with an interactive graphics capability, but this ability was developed specific to the NASA Langley Research Center CRT display system and its associated software. This part of the system is considered inoperative in the distributed code because of the lack of supporting software. A user may be able to revive the interactive graphics segment if they already have existing interactive graphics capabilities. The program also provides off-line plotting abilities that require a Calcomp plotter. The Langley Research Center graphic library routines are provided in relocatable form as a plot library. This program is written in FORTRAN and has been implemented on the CDC 6000 series computer with a central memory requirement of approximately 54K (octal) of 60 bit words. This program was developed in 1976.

831. BARNHART, PAUL J.: **A supersonic through-flow fan engine airframe integration study.** AIAA PAPER 89-2140 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Conference, Seattle, WA, July 31-Aug. 2, 1989. 10 p., 1989 89A50802

A study is undertaken to investigate the engine airframe integration effects for supersonic through-flow fan engines installed on a Mach 3.20 supersonic cruise vehicle. Six

different supersonic through-flow fan engine installations covering the effects of engine size, nacelle contour, nacelle placement, and approximate bypass plume effects are presented. The different supersonic through-flow fan installations are compared with a conventional turbine bypass engine configuration on the same basic airframe. The supersonic through-flow fan engine integrations are shown to be comparable to the turbine bypass engine configuration on the basis of installed nacelle wave drag. The supersonic through-flow fan engine airframe integrated vehicles have superior aerodynamic performance on the basis of maximum lift-to-drag ratio than the turbine bypass engine installation over the entire operating Mach number range from 1.10 to 3.20. When approximate bypass plume modeling is included, the supersonic through-flow fan engine configuration shows even larger improvements over the turbine bypass engine configuration.

832. BARNHART, PAUL J.: **A supersonic through-flow fan engine airframe integration study.** NASA-CR-185140 E-5068 NAS 1.26:185140 AIAA-89-2140 1989. 90N10004

Engine airframe integration effects are investigated for supersonic through-flow fan engines installed on a Mach 3.20 supersonic cruise vehicle. Six different supersonic through-flow fan engine installations covering the effects of engine size, nacelle contour, nacelle placement, and approximate bypass plume effects are presented. The different supersonic through-flow fan installations are compared with a conventional turbine bypass engine configuration on the same basic airframe. The supersonic through-flow fan engine integrations are shown to be comparable to the turbine bypass engine configuration on the basis of installed nacelle wave drag. The supersonic through-flow fan engine airframe integrated vehicles have superior aerodynamic performance on the basis of maximum lift-to-drag ratio than the turbine bypass engine installation over the entire operating Mach number range from 1.10 to 3.20. When approximate bypass plume modeling is included, the supersonic through-flow fan engine configuration shows even larger improvements over the turbine bypass engine configuration.

833. WIDDISION, C. A.; SCHREFFLER, E. S.; HOSKING, C. W.: **Aircraft synthesis with propulsion installation effects.** AIAA PAPER 88-4404 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Atlanta, GA, Sept. 7-9, 1988. 8 p. 1988. 88A51929

The Propulsion/Weapon System Interaction Model computer program for rapid evaluation of a wide variety of aircraft configurations, in any desired mission application, is structured to allow the user to select from a library of existing generic configurations and propulsion systems. In addition to assessing the propulsion/airframe interaction of different types of engine installations, a flexible mission definition procedure is used which allows the calculation of virtually any mission profile. The propulsion-airframe interactions encompass the effects of inlet losses, nozzle gross thrust, and aft-body drag, on the net thrust of the propulsion system.

834. SEDDON, J.: **Transonic cowl design.** In its Intake Aerodynamics, Volume 1, 23 p (See 89N16738 09-02) 1988. 89N16746

Transonic cowl design is discussed in the context of external drag of engine nacelles on high-subsonic transport aircraft. The principal concern arises because at high subsonic speeds the airflow over the intake cowl, and in other regions of an overall podded installation, becomes locally supersonic, giving rise to shock waves and possible boundary layer separation. Both these features can lead to substantial increases in aircraft drag. Drag below the critical Mach number (where flow locally reaches sonic speed) and subcritical cowl design are treated.

835. POGREBNAIA, T. V.; SAMSONOV, V. V.: **Calculation of supersonic flow past a three-dimensional configuration using integral relationships**. TsAGI, Uchenye Zapiski (ISSN 0321-3429), vol. 15, no. 5, 1984, p. 119-124. In Russian. 86A13423

A numerical method is proposed which can be used to determine the distributed and overall aerodynamic characteristics in supersonic flow past a system of arbitrary surfaces (wings, tail unit, air intake, and the vehicle as a whole) in the framework of the linear approximation. A uniform accuracy of aerodynamic-load determination is assured on all the surfaces. The boundary value problem concerning the determination of surface loads is reduced to a system of integral equations, which are solved by the method of successive approximations.

836. ERDOS, J. I.; RAY, R.; MANDEL, M.: **Aeromechanical applications of favorable supersonic interference. Volume 3: Performance of a Mach 3 aircraft concept based on nacelle-wing interference (U)** AD-C032942L GASL-TR-266 AFWAL-TR-82-3020-VOL-3 1983. 84X72794 <u>US GOV AGENCIES</u>

837. WAGGONER, E. G.: **Computational analysis for an advanced transport configuration with engine nacelle.** AIAA PAPER 83-1851 American Institute of Aeronautics and Astronautics, Applied Aerodynamics Conference, Danvers, MA, July 13-15, 1983. 13 p. 83A38679

A small-disturbance transonic analysis code is used to calculate the flow-field effects of adding an engine nacelle to a wing/body configuration. Analyses are performed on an advanced transport configuration with and without engine nacelles. Two nacelle shapes are analyzed and the effects of the nacelle installation on pressure distributions are compared with experimental results obtained by shifting the nacelle longitudinally and vertically relative to the wing. Effects of varying the nacelle installation yaw angle are also analyzed and compared with experimental data. These comparisons show that the analysis code is adequately sensitive to variations in nacelle shape, longitudinal and vertical location beneath the wing, and the nacelle installation yaw angle. Results indicate that the code can be used as an effective guide during the design process.

838. BLISSEL, W.; KULFAN, R.: **Analysis of transonic nacelle interference**. In its Advan. Concept Studies for Supersonic Vehicles, 43 p (See 82X10002 01-01) 1981. 82X10004 <u>US GOV AGENCIES AND CONTRACTORS</u>

Studies to improve correlations between theoretical predictions and test results assessing shock-spillage interference effects on nacelle-airframe interference are summarized. Effects associated with the aerodynamic efficiency of the propulsion system's installation and operation at subsonic through supersonic speeds are considered. Specific areas discussed are: (1) sensitivity of the capture streamtube shape on predicted effects of reduced mass-flow on nacelle-airframe interference, (2) alternative procedures for calculating interference effects using streamtube shapes predicted by flow analysis methods, and (3) comparisons of predicted oblique-shock and normal-shock spillage effects on nacelle-airframe interference. Results of flow analyses imply that oblique-shock spillage interference effects are milder than normal-shock spillage interference effects.

839. MIDDLETON, W. D.; LUNDRY, J. L.: **A system for aerodynamic design and analysis of supersonic aircraft. Part 1: General description and theoretical development.** NASA-CR-3351 D6-41840-1 1980. 81N14970

An integrated system of computer programs was developed for the design and analysis of supersonic configurations. The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients.

840. MIDDLETON, W. D.; LUNDRY, J. L.; COLEMAN, R. G.: **A system for aerodynamic design and analysis of supersonic aircraft. Part 2: User's manual.** NASA-CR-3352 D6-41840-2 1980. 81N13920

The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients. Interactive graphics were included in the system to display or edit input and to permit monitoring and readout of program results.

841. MIDDLETON, W. D.; LUNDRY, J. L.; COLEMAN, R. G.: **A system for aerodynamic design and analysis of supersonic aircraft. Part 3: Computer program description.** NASA-CR-3353 D6-41840-3 1980. 81N14971

The computer program documentation for the design and analysis of supersonic configurations is presented. Schematics and block diagrams of the major program structure, together with subroutine descriptions for each module are included.

842. MIDDLETON, W. D.; LUNDRY, J. L.: **A system for aerodynamic design and analysis of supersonic aircraft. Part 4: Test cases.** NASA-CR-3354 D6-41840-4 1980. 81N15977

An integrated system of computer programs was developed for the design and analysis of supersonic configurations. The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients. Interactive graphics are optional at the user's request. Representative test cases and associated program output are presented.

843. KULFAN, R. M.: **Prediction of nacelle aerodynamic interference effects at low supersonic Mach numbers**. In NASA Langley Res. Center Supersonic Cruise Res. 1979, Pt. 1, p 171-203 (See 81N17981 09-01) March 1980 81N17988

The accuracy of analytical predictions of nacelle aerodynamic interference effects at low supersonic speeds are studied by means of test versus theory comparisons. Comparisons shown include: (1) isolated wing body lift, drag, and pitching moments; (2) isolated nacelle drag and pressure distributions; (3) nacelle interference shock wave patterns and pressure distributions on the wing lower surface; (4) nacelle interference effects on wing body lift, drag, and pitching moments; and (5) total installed nacelle interference effects on lift, drag, and pitching moment. The comparisons also illustrate effects of nacelle location, nacelle spillage,angle of attack, and Mach numbers on the aerodynamic interference. The initial results seem to indicate that the methods can satisfactorily predict lift, drag, pitching moment, and pressure distributions of installed engine nacelles at low supersonic Mach numbers with mass flow ratios from 0.7 to 1.0 for configurations typical of efficient supersonic cruise airplanes.

844. SMYTH, R.: **Computer programs for the design and performance evaluation of nacelles for high bypass-ratio engines**. In AGARD The Use of Computers as a Design Tool, 21 p (See 80N21243 12-01) 1980. 80N21270

The use of the computer as a design tool for the different stages of nacelle development and integration with the airframe is discussed. Trends in propulsion system development and methods of calculation suitable for computerized work with nacelles are reported. The computer program developed for nacelle synthesis consists of an executive program which uses program modules based on the engine component breakdown. The main program modules are the geometrical requirements, the inlet definition, the nozzle and afterbody definition, and the flow calculation. Each program module and its function in the executive program is discussed. The use of the computer program for the performance evaluation of nacelles during the aircraft design process is described.

845. BOPPE, C. W.; AIDALA, P. V.: **Complex configuration analysis at transonic speeds**. In AGARD Subsonic/Transonic Configuration Aerodyn., 13 p (See 81N15991 07-01) 1980. 81N16016

Advanced performance requirements of new combat and transport aircraft together with design time constraints intensify the development and application of three dimensional computational analyses. A computational method which was developed for the specific purpose of providing an engineering analysis of complex aircraft configurations at transonic speeds. Particular attention is given to the recently incorporated wing viscous interaction and canard capabilities. The treatment of fuselage fairings, nacelles, and pylons is reviewed. The means for keeping computing resources at reasonable levels are identified. Three configurations were selected for correlations with experimental data. Taken together, the comparisons illustrate the full extent of current analysis capabilities. The configurations include: (1) a wing fuselage canard fighter; (2) a transport with fuselage fairings, four nacelles, four pylons; and (3) a space vehicle which includes an external fuel tank and rocket boosters (transonic launch configuration).

846. KUHN, G. D.; MCMILLAN, O. J.; PERKINS, S. C., JR.; PERKINS, E. W.: **Evaluation of methods for prediction of propulsion system drag.** AIAA PAPER 79-1148 AIAA, SAE, and ASME, Joint Propulsion Conference, 15th, Las Vegas, Nev., June 18-20, 1979, AIAA 13 p. 1979. 79A38961

The results of a study directed toward compilation of a theoretical and experimental data base covering inlet/airframe and nozzle afterbody integration are described, with the major emphasis on the evaluation of the adequacy for preliminary design purposes of the data base for afterbody/propulsion system interference effects. Prediction methods that exist for afterbody/ airframe interference effects are evaluated with respect to the requirements of breadth, ease of application and accuracy that are important for preliminary design.

847. KOWALSKI, E. J.: **Computer code for estimating installed performance of aircraft gas turbine engines.** Volume 1: Final report.: NASA-CR-159691 D180-25481-1-VOL-1 1979. 80N13043

A computerized method which utilizes the engine performance data is described. The method estimates the installed performance of aircraft gas turbine engines. This installation includes: engine weight and dimensions,inlet and nozzle internal performance and drag, inlet and nacelle weight, and nacelle drag.

848. JOHNSON, E. S.: **Advanced technology engine integration/acoustic study.** NASA-CR-159298 MDC-J4601 1978. 80X10128 US GOV AGENCIES AND CONTRACTORS

The integration and evaluation near term and advanced technology low bypass engines and advanced technology variable cycle engines using the MDC 2.2M baseline supersonic airplane is reported. The mission and acoustics performance of the airplane with each engine installed is determined. An analysis of each engine/airplane combination is conducted to determine the effect of the engine on the configuration, weight, strength, mission performance, and resulting noise. Resulting capabilities included ranges up to 4150 n.mi. for the near term low bypass engines, 4800 n.mi. for the intermediate term (1982) low bypass engines, and 4900 n.mi. for the intermediate term advance technology variable cycle engines.

849. WILSON, J. R.; BENSON, J. L.: **Propulsion system airframe integration studies - Advanced supersonic transport.** AIAA PAPER 78-1053 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 7 p. 1978. 78A48488

One of the objectives of the considered integration studies is related to the identification of engine/airframe configurations which offer the best performance potential within environmental constraints. Other objectives include the identification of engine cycle and geometry improvements, the development of practical preliminary designs of most promising configurations, and the identification of test and development program requirements. The variables examined in the study are related to the engine nacelle location, the inlet configuration, the engine cycle/configuration, engine-inlet airflow match, engine thrust schedule, and engine accessory location. Attention is given to propulsion system configurations, tradeoff studies, engine-inlet matching studies, aspects of nacelle design integration, and engine operational procedures.

850. WILSON, J. R.; WRIGHT, B. R.: **Airframe/engine integration with variable cycle engines.** AIAA PAPER 77-798 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 13th, Orlando, Fla., July 11-13, 1977, AIAA 8 p. 1977. 77A41961

The paper studies the feasibility of using variable cycle engines, which have the ability to operate like turbofans during subsonic cruise and like turbojets at supersonic cruise, to regulate airflow and better match the engine with the inlet and reduce off-design penalties for second generation SST designs employing the over/under concept of engine installation. A study of engine performance penalties related to inlet matching was performed on a advanced SST baseline aircraft with under/over nacelles containing VCE's with two different mixed compression inlet designs: a translating centerbody axisymmetric inlet, and a two-dimensional, articulated centerbody, vertical wedge. Mission analyses show that the variable geometry features of VCE's allow engine airflow to be scheduled to match either type of inlet for minimum installations costs.

851. MIDDLETON, W. D.; LUNDRY, J. L.; COLEMAN, R. G.: **A computational system for aerodynamic design and analysis of supersonic aircraft.** Part 2: User's manual. NASA-CR-2716 D6-43798-2 1976. 77N11005

An integrated system of computer programs was developed for the design and analysis of supersonic configurations. The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients. Interactive graphics are optional at the user's request. This user's manual contains a description of the system, an explanation of its usage, the input definition, and example output.

852. MIDDLETON, W. D.; LUNDRY, J. L.: **A computational system for aerodynamic design and analysis of supersonic aircraft. Part 1: General description and theoretical development.** NASA-CR-2715 D6-43798-1-PT-1 1976. 76N28161

An integrated system of computer programs was developed for the design and analysis of supersonic configurations. The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients. Interactive graphics are optional at the user's request. Schematics of the program structure and the individual overlays and subroutines are described.

853. MIDDLETON, W. D.; LUNDRY, J. L.; COLEMAN, R. G.: **A computational system for aerodynamic design and analysis of supersonic aircraft. Part 3: Computer program description.** NASA-CR-2717 D6-43798-3-PT-3 1976. 76N28162
For abstract, see Vol. 1.

854. MORRIS, S. J., JR.; NELMS, W. P., JR.; BAILEY, R. O.: **A simplified analysis of propulsion installation losses for computerized aircraft design.** NASA-TM-X-73136 A-6608 1976. 77N16016

A simplified method is presented for computing the installation losses of aircraft gas turbine propulsion systems. The method has been programmed for use in computer aided conceptual aircraft design studies that cover a broad range of Mach numbers and altitudes. The items computed are: inlet size, pressure recovery, additive drag, subsonic spillage drag, bleed and bypass drags, auxiliary air systems drag, boundary-layer diverter drag, nozzle boattail drag, and the interference drag on the region adjacent to multiple nozzle installations. The methods for computing each of these installation effects are described and computer codes for the calculation of these effects are furnished. The results of these methods are compared with selected data for the F-5A and other aircraft. The computer program can be used with uninstalled engine performance information which is currently supplied by a cycle analysis program. The program, including comments, is about 600 FORTRAN statements long, and uses both theoretical and empirical techniques.

855. MILLER, D. S.; MIDDLETON, W. D.: **An integrated system for the aerodynamic design and analysis of supersonic aircraft** 1975. 76N10046
An integrated system of computer programs is described. The goals of the system were to develop an easily used supersonic design and analysis capability with recognition of the need for constraints on linear theory to provide physical realism and with inclusion of interactive graphics capability for increased control over the design and analysis iteration cycles.

856. WITTMANN, M.: **Investigation of the mutual interference of wing/engine combinations**. ESA-TT-217 DLR-FB-74-32. 1975. 76N24184

The mutual interference between wing and engine nacelle is significant since aircraft engines are often arranged either above or below the wing. For theoretical calculations the wing is represented by a flat plate and the engine nacelle by a cylinder composed of source and vortex singularities. The normal velocity components induced on the wing by the nacelle are simulated by additional singularities on the wing in order to obtain a first approximation of the modified pressure distribution. Experimental results are represented for nine wing/nacelle combinations and three angles of attack. Three different intake blockages are also considered. For several cases the theoretical and experimental results are compared.

857. BONNER, E.; ROE, M. H.; TYSON, R. M.; MAIRS, R. Y. : **Influence of propulsion system size, shape, and location on supersonic aircraft design**. NASA-CR-132544 1974. 75N14747

The effects of various propulsion system parameters on the characteristics of a supersonic transport were investigated. The effects of arbitrarily scaling engine size on wave drag, friction drag, drag-due-to-lift, wing sizing, airplane balance, and airplane weight were studied. These evaluations were made for two families of nacelle shapes, resulting from typical turbojet and turbofan installations. Also examined were effects of nacelle location, and the wing camber plane deformations required to cancel the nacelle interference pressure field at cruise Mach number (2.7 M) were determined. The most drag-sensitive parameter is found to be nacelle shape. Similarly, wing deformation requirements are found to be primarily affected by nacelle shape. Effects of engine size variations are noted primarily in airplane gross weight.

858. BALL, W. H.: **Rapid calculation of propulsion system installation corrections.** AIAA PAPER 74-1174 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 10th, San Diego, Calif., Oct. 21-23, 1974, AIAA 10p. 1974. 75A10324

A calculation procedure has been developed to help evaluate installed propulsion system performance during preliminary studies of advanced military aircraft. The method is based on experimental and theoretical data relating geometric and aerodynamic variables to spillage drag, pressure recovery boundary layer bleed drag, boattail drag, and nozzle interference effects. The procedure accounts for throttle-dependent effects on total pressure recovery and drag. Maps of standardized format, consistent with an acceptable force accounting system, are used to provide recovery and drag as a function of engine corrected airflow. A description is presented of the computer program that uses the calculation procedure to correct uninstalled engine data for installation effects.

Results are presented to show the agreement obtained between calculated and measured installation corrections.

8.5 NACELLES

859. KNUDSEN, A. W.: **Advanced supersonic transport nacelle installation drag increment.** LEW-12786 1990 90M10580

This program was developed to determine nacelle incremental drag for the NASA arrow-wing configuration of an advanced supersonic transport. It has been recognized that one of the more sensitive problems in the design of a successful supersonic cruising aircraft is that of airframe/engine integration. Recent studies have shown that drag, weight, and wing camber plane warping are very sensitive to nacelle size and shape. It is important that the engine designer be aware of this sensitivity to engine geometry. Some engine geometry control can be achieved by the designer with no penalty in engine performance, although on a total system basis, some engine performance degradation may be accepted in trade for reduced drag. This program should prove useful by providing a rapid approximate methodology for comparing alternative propulsion system designs for supersonic transports. This program uses a table look-up and interpolation procedure to determine the nacelle incremental drag. Wave drag is represented as a function of free stream Mach number and six independent variables, each a function of nacelle shape and size. Friction drag is defined by four independent variables, each a function of engine geometry. These independent variables are used to determine drag values using a table of existing drag data points. For drag values not directly available, the program interpolates, or extrapolates, among the available table values. The program determines a set of data points for use when calculating the drag associated with a given set of values of the independent variables. Once these data points are found, a cubic equation is fitted and the drag increments are determined. This program is written in FORTRAN IV for batch execution and has been implemented on an IBM 370 series computer with a central memory requirement of approximately 40K of 8 bit bytes. This program was developed in 1976.

860. MIDDLETON, W. D.: **Aerodynamic design and analysis of supersonic aircraft.** LAR-12237 90M10337

This package is an integrated system of computer programs developed for the design and analysis of supersonic configurations. The system uses linearized theory methods for the calculation of surface pressures and supersonic area rule concepts in combination with linearized theory for calculation of aerodynamic force coefficients. The goal of the integrated system is to provide an easily used supersonic design and analysis capability, with recognition of the need for constraints on linear theory methods to provide physical realism. This package should prove useful in the design and analysis of any type of supersonic configuration. The integrated system consists of an executive "driver" and seven basic computer programs, including a geometry input module. The individual modules provide data for configuration design or analysis. Skin friction is computed using turbulent flat plate theory. Wave drag is calculated from either far-field (supersonic area rule) or near-field (surface pressure integration) methods. The far-field method is used for wave drag coefficient calculations and for fuselage optimization according to area rule concepts. The near-field is used primarily as an analysis tool, where detailed pressure distributions are of interest. Lifting pressure, drag due to lift, pitching moment, and trim drag are computed from the lift analysis program which breaks arbitrary wing/ fuselage/ canard/ nacelles/ horizontal tail configurations into a mosaic of "Mach-box" rectilinear elements, which are employed in linear theory solutions. A complementary wing design and optimization program solves for the wing shape required to support an optimized pressure distribution at a specified flight condition. A geometry module handles all configuration geometry for the system. All "paneling" of configuration for theoretical analyses is accomplished within the programs, and the user prepares only "drawing-type" geometry specifications for input. A plot module draws configuration pictures according to size and view request. Thus the basis of the system is supersonic linearized theory, modified with the "Whitham" correction to disturbance positioning being used in the propagation of body pressure fields, an optional limiting pressure feature to control the permissible level of upper surface pressure coefficient, and a constraint to limit the upper surface streamwise pressure gradient. The entire design and analysis system is a single overlaid program. The executive level of the system controls module execution by means of special identification cards in the input data. Transfer of data in the system between modules is handled by disk storage and common blocks. The system was developed with an interactive graphics capability, but this ability was developed specific to the NASA Langley Research Center CRT display system and its associated software. This part of the system is considered inoperative in the distributed code because of the lack of supporting software. A user may be able to revive the interactive graphics segment if they already have existing interactive graphics capabilities. The program also provides off-line

plotting abilities that require a Calcomp plotter. The Langley Research Center graphic library routines are provided in relocatable form as a plot library. This program is written in FORTRAN and has been implemented on the CDC 6000 series computer with a central memory requirement of approximately 54K (octal) of 60 bit words. This program was developed in 1976.

861. BARNHART, PAUL J.: **A supersonic through-flow fan engine airframe integration study.** AIAA PAPER 89-2140 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Conference, Seattle, WA, July 31-Aug. 2, 1989. 10 p., 1989 89A50802

A study is undertaken to investigate the engine airframe integration effects for supersonic through-flow fan engines installed on a Mach 3.20 supersonic cruise vehicle. Six different supersonic through-flow fan engine installations covering the effects of engine size, nacelle contour, nacelle placement, and approximate bypass plume effects are presented. The different supersonic through-flow fan installations are compared with a conventional turbine bypass engine configuration on the same basic airframe. The supersonic through-flow fan engine integrations are shown to be comparable to the turbine bypass engine configuration on the basis of installed nacelle wave drag. The supersonic through-flow fan engine airframe integrated vehicles have superior aerodynamic performance on the basis of maximum lift-to-drag ratio than the turbine bypass engine installation over the entire operating Mach number range from 1.10 to 3.20. When approximate bypass plume modeling is included, the supersonic through-flow fan engine configuration shows even larger improvements over the turbine bypass engine configuration.

862. BARNHART, PAUL J.: **A supersonic through-flow fan engine airframe integration study.** NASA-CR-185140 E-5068 NAS 1.26:185140 AIAA-89-2140 1989. 90N10004

Engine airframe integration effects are investigated for supersonic through-flow fan engines installed on a Mach 3.20 supersonic cruise vehicle. Six different supersonic through-flow fan engine installations covering the effects of engine size, nacelle contour, nacelle placement, and approximate bypass plume effects are presented. The different supersonic through-flow fan installations are compared with a conventional turbine bypass engine configuration on the same basic airframe. The supersonic through-flow fan engine integrations are shown to be comparable to the turbine bypass engine configuration on the basis of installed nacelle wave drag. The supersonic through-flow fan engine airframe integrated vehicles have superior aerodynamic performance on the basis of maximum lift-to-drag ratio than the turbine bypass engine installation over the entire operating Mach number range from 1.10 to 3.20. When approximate bypass plume modeling is included, the supersonic through-flow fan engine configuration shows even larger improvements over the turbine bypass engine configuration.

863. SUIKAT, REINER; FAROKHI, SAEED: **Method to optimize nacelle shape in a supersonic cruise aircraft**. (AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Saint Louis, MO, Sept. 14-16, 1987, AIAA Paper 87-2865) Journal of Aircraft (ISSN 0021-8669), vol. 25, Aug. 1988, p. 717-723. Previously cited in issue 03, p. 286, Accession no. 88A14254. 89A12558

864. RADESPIEL, R.; HORSTMANN, K. H.; REDEKER, G.: **Feasibility study on the design of a laminar flow nacelle.** AIAA PAPER 89-0640 AIAA, Aerospace Sciences Meeting, 27th, Reno, NV, Jan. 9-12, 1989. 12 p. 89A25506

This paper describes the design of a laminar flow nacelle. By means of natural laminar flow, e.g., nacelle contouring, laminar boundary layers on the nacelle surface can be maintained up to 60 percent of the nacelle length at cruise flight conditions. As well at take-off and landing conditions the inlet flow and the outside flow is free of flow separation. The overall drag coefficient of an aircraft equipped with two laminar flow nacelles is estimated to be reduced at cruise flight by Delta c(D) of about 0.0011.

865. SEDDON, J.: **Transonic cowl design.** In its Intake Aerodynamics, Volume 1, 23 p (See 89N16738 09-02) 1988. 89N16746

Transonic cowl design is discussed in the context of external drag of engine nacelles on high-subsonic transport aircraft. The principal concern arises because at high subsonic speeds the airflow over the intake cowl, and in other regions of an overall podded installation, becomes locally supersonic, giving rise to shock waves and possible boundary layer separation. Both these features can lead to substantial increases in aircraft drag. Drag below the critical Mach number (where flow locally reaches sonic speed) and subcritical cowl design are treated.

866. SUIKAT, REINER; FAROKHI, SAEED: **A method to optimize nacelle shape in a supersonic cruise aircraft.** AIAA PAPER 87-2865 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Meeting, Saint Louis, MO, Sept. 14-16, 1987. 8 p. 88A14254

A computer program is developed to optimize the shape of a nacelle installed in a supersonic aircraft for minimum drag. The program is also capable of optimizing the wing camber of the same aircraft. As a unique feature, the present code accounts for the aerodynamic forces on the entire airplane, in contrast to previous wing camber optimization codes which included only the wing forces. The program is based on a panel method analysis code by Woodward and the accuracy of the program is checked with the available wind tunnel data on isolated components as well as full configurations. The computed results are in general agreement with the available data. The results of several optimization test runs are presented and show agreement with trends predicted by other researchers based on theoretical and experimental studies. At higher angles of attack,when supersonic vortex lift becomes significant, the analysis code underpredicts the aircraft lift coefficient.

867. BOPPE, CHARLES W.: **Aerodynamic analysis for aircraft with nacelles, pylons, and winglets at transonic speeds.**: NASA-CR-4066 NAS 1.26:4066 April 1987 87N18538

A computational method has been developed to provide an analysis for complex realistic aircraft configurations at transonic speeds. Wing-fuselage configurations with various combinations of pods, pylons, nacelles, and winglets can be analyzed along with simpler shapes such as airfoils, isolated wings, and isolated bodies. The flexibility required for the treatment of such diverse geometries is obtained by using a multiple nested grid approach in the finite-difference relaxation scheme. Aircraft components (and their grid systems) can be added or removed as required. As a result, the computational method can be used in the same manner as a wind tunnel to study high-speed aerodynamic interference effects. The multiple grid approach also provides high boundary point density/cost ratio. High resolution pressure distributions can be obtained. Computed results are correlated with wind tunnel and flight data using four different transport configurations. Experimental/computational component interference effects are included for cases where data are available. The computer code used for these comparisons is described in the appendices.

868. HENDERSON, WILLIAM P.: **Propulsion-airframe integration for commercial and military aircraft.** SAE PAPER 872411 IN: International Pacific Air and Space Technology Conference, Melbourne, Australia, Nov. 13-17, 1987, Proceedings (89A10627 01-01). Warrendale, PA, Society of Automotive Engineers, Inc., 1988, p. 133-144. 89A10637

A significant level of research is ongoing at NASA's Langley Research Center on integrating the propulsion system with the aircraft. This program has included nacelle/pylon/wing integration for turbofan transports, propeller/nacelle/wing integration for turboprop transports, and nozzle/afterbody/empennage integration for high performance aircraft. The studies included in this paper focus more specifically on pylon shaping and nacelle location studies for turbofan transports, nacelle and wing contouring and propeller location effects for turboprop transports, and nozzle shaping and empennage effects for high performance aircraft. The studies were primarily conducted in NASA Langley's 16-Foot Transonic Tunnel at Mach numbers up to 1.20. Some higher Mach number data obtained at NASA's Lewis Research Center is also included.

869. NAKADATE, MASAAKI; NAGASHIMA, HIDEFUMI; YANAGIZAWA, MITSUNORI: **Computation of nacelle interference using boundary element method.** In National Aerospace Lab., Proceedings of the 4th NAL Sýmposium on Aircraft Computational Aerodynamics, p 107-120 (see 88N13253 05-02) 1986. 88N13267

The aerodynamic interference problem of jet transport aircraft due to the close coupling between nacelle and wing is one of the major concerns of aerodynamic engineers. At the research level, the Navier-Stokes code is beginning to be applied to such a problem. At the engineering level the application of the panel method is more practical. This paper presents the results of applying the Boundary Element Method code to the analysis of nacelle interference of a practical jet transport.

870. MURTHY, S. N. B.; PAYNTER, G. C.: **Numerical methods for engine-airframe integration.** New York, American Institute of Aeronautics and Astronautics, Inc. (Progress in Astronautics and Aeronautics. Volume 102), 1986, 554 p. For individual items see 87A11777 to 87A11781. 1986. 87A11776

Various papers on numerical methods for engine-airframe integration are presented. The individual topics considered include: scientific computing environment for the 1980s,

overview of prediction of complex turbulent flows, numerical solutions of the compressible Navier-Stokes equations, elements of computational engine airframe integrations, computational requirements for efficient engine installation, application of CAE and CFD techniques to complete tactical missile design, CFD applications to engine/airframe integration, and application of a second-generation low-order panel methods to powerplant installation studies. Also addressed are: three-dimensional flow analysis of turboprop inlet and nacelle configurations, application of computational methods to the design of large turbofan engine nacelles, comparison of full potential and Euler solution algorithms for aeropropulsive flow field computations, subsonic/transonic, supersonic nozzle flows and nozzle integration, subsonic/transonic prediction capabilities for nozzle/afterbody configurations, three-dimensional viscous design methodology of supersonic inlet systems for advanced technology aircraft, and a user's technology assessment.

871. LAMB, MILTON; ABEYOUNIS, WILLIAM K.; PATTERSON, JAMES C., JR.; RE, RICHARD J.: **Natural laminar flow nacelle for transport aircraft**. In its Langley Symposium on Aerodynamics, Volume 1, p 445-460 (See 88N14926 07-01) 1986. 88N14949

The potential of laminar flow nacelles for reducing installed engine/nacelle drag was studied. The purpose was twofold: to experimentally verify a method for designing laminar flow nacelles and to determine the effect of installation on the extent of laminar flow on the nacelle and on the nacelle pressure distributions. The results of the isolated nacelle tests illustrated that laminar flow could be maintained over the desired length. Installing the nacelles on wing/pylon did not alter the extent of laminar flow occurring on the nacelles. The results illustrated that a significant drag reduction was achieved with this laminar flow design. Further drag reduction could be obtained with proper nacelle location and pylon contouring.

872. SHANKAR, V.; SZEMA, K. Y.: **Nonlinear potential analysis techniques for supersonic aerodynamic design.** NASA-CR-172507 NAS 1.26:172507 1985. 87N17670

A numerical method based on the conservation form of the full potential equation has been applied to the problem of three-dimensional supersonic flows with embedded subsonic regions. The governing equation is cast in a nonorthogonal coordinate system, and the theory of characteristics is used to accurately monitor the type-dependent flow field. A conservative switching scheme is employed to transition from the supersonic marching procedure to a subsonic relaxation algorithm and vice versa. The newly developed computer program can handle arbitrary geometries with fuselage, canard, wing, flow through nacelle, vertical tail and wake components at combined angles of attack and sideslip. Results are obtained for a variety of configurations that include a Langley advanced fighter concept with fuselage centerline nacelle, Rockwell's Advanced Tactical Fighter (ATF) with wing mounted nacelles, and the Shuttle Orbiter configuration. Comparisons with available experiments were good.

873. LAMB, MILTON; CARLSON, JOHN R.; PENDERGRAFT, ODIS C., JR.: **Integration effects of D-shaped, underwing, aft-mounted, separate-flow, flow-through nacelles on a high-wing transport.** NASA-TM-4018 L-16342 NAS 1.15:4018 1987. 88N10773

An experimental investigation was conducted in the Langley 16-Foot Transonic Tunnel at freestream Mach numbers from 0.70 to 0.82 and angles of attack from -3.0 to 4.0 deg to determine the integration effects of D-shaped, underwing, aft-mounted, separate-flow, flow-through nacelles on a high-wing transonic transport configuration. The results showed that the aft-mounted nacelle/pylon produced an increase in lift over that of the wing-body configuration by pressurizing much of the wing lower surface in front of the pylon. For the D-shaped nacelle, a substantial region of supersonic flow over the wing, aft of the lip of the nacelle, canceled the reduction in drag caused by the increase in pressures ahead of the lip, to increase interference and form drag compared with a similar circular-shaped nacelle. The installed drag of the D=shaped nacelle was essentially the same as that of an aft-mounted circular nacelle from a previous investigation.

874. CARLSON, JOHN R.; LAMB, MILTON: **Integration effects of pylon geometry and rearward mounted nacelles for a high-wing transport**. AIAA PAPER 87-1920 AIAA, SAE, ASME, and ASEE, Joint Propulsion Conference, 23rd, San Diego, CA, June 29-July 2, 1987. 11 p. 87A45300

Results of a wind-tunnel study of the effect of pylon cross-sectional shape and tow angle on airplane drag and an aft-mounted nacelle are presented. The 1/24-scale wide-body high-wing transport model was tested in the Langley 16-Foot Transonic Tunnel at free-stream Mach 0.7-0.8 and angles of attack from -3 to 4 degrees. A compression-type pylon is found to have the lowest drag at both Mach 0.7 and 0.8 and to be capable of suppressing the velocities in the inboard region of the

pylon-wing junction, reducing the extent of supersonic flow and the probability of flow separation. It is also shown that the D-shaped aft-mounted nacelle has a low interference drag, as do previously tested circular nacelles in the same position.

875. ABEYOUNIS, W. K.; PATTERSON, J. C., JR.: **Effect of underwing aft-mounted nacelles on the longitudinal aerodynamic characteristics of a high-wing transport airplane.** NASA-TP-2447 L-15664 NAS 1.60:2447 1985. 86N20345

As part of a propulsion/airframe integration program, tests were conducted in the Langley 16-Foot Transonic Tunnel to determine the longitudinal aerodynamic effects of installing flow through engine nacelles in the aft underwing position of a high wing transonic transfer airplane. Mixed flow nacelles with circular and D-shaped inlets were tested at free stream Mach numbers from 0.70 to 0.85 and angles of attack from -2.5 deg to 4.0 deg. The aerodynamic effects of installing antishock bodies on the wing and nacelle upper surfaces as a means of attaching and supporting nacelles in an extreme aft position were investigated.

876. CARLSON, J. R.; PENDERGRAFT, O. C., JR.; BARTLETT, G. R.: **Comparison of advanced turboprop installation on swept and unswept supercritical wings at transonic speeds.**: AIAA PAPER 85-1264 AIAA,SAE, ASME, and ASEE, Joint Propulsion Conference, 21st, Monterey, CA, July 8-10, 1985. 7 p. July 1985 85A39686

A series of wind-tunnel investigations were conducted to determine the aerodynamic interference associated with the over wing and under wing installation of a turboprop nacelle on 20 deg swept and unswept supercritical wings. The purpose of the investigations was to increase the understanding of the flow interactions involved with the nacelle turboprop integration and to obtain experimental data for the verification of computational prediction techniques. The models were tested in the Langley 16-Foot Transonic Tunnel at Mach numbers from 0.50 to 0.80 and at angles-of-attack from 0 to 5 deg. In addition, data at several propeller pitch angles and advance ratio settings were obtained. This paper which presents only the results of the over-the-wing nacelle installations shows that wing sweep had considerable influence on the installation interference. Large scale flow separation was observed on the swept wing at M = 0.8. Less severe effects were observed at M = 0.7 on the swept wing and for both M = 0.7 and 0.8 on the unswept wing.

877. SMITH, K. L.; KERR, W. B.; HARTMANN, G. L.; SKIRA, C. LAMB, M.; AABEYOUNIS, W. K.; PATTERSON, J. C., JR.: **Nacelle/pylon/wing integration on a transport model with a natural laminar flow nacelle.** NASA-TP-2439 L-15907 NAS 1.60:2439 1985. 85N29924

Tests were conducted in the Langley 16-Foot Transonic Tunnel at free-stream Mach numbers from 0.70 to 0.82 and angles of attack from -2.5 deg to 4.0 deg to determine if nacelle/pylon/wing integration affects the achievement of natural laminar flow on a long-duct flow-through nacelle for a high-wing transonic transport configuration. In order to fully assess the integration effect on a nacelle designed to achieve laminar flow, the effects of fixed and free nacelle transitions as well as nacelle longitudinal position and pylon contouring were obtained. The results indicate that the ability to achieve laminar flow on the nacelle is not significantly altered by nacelle/pylon/wing integration. The increment in installed drag between free and fixed transition for the nacelles on symmetrical pylons is essentially the calculated differences between turbulent and laminar flow on the nacelles. The installed drag of the contoured pylon is less than that of the symmetrical pylon. The installed drag for the nacelles in a rearward position is greater than that for the nacelles in a forward position.

878. YOUNGHANS, J. L.; LAHTI, D. J.: **Analytical and experimental studies on natural laminar flow nacelles.** AIAA PAPER 84-0034 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 11 p. 84A17839

High speed proof of concept testing of a scale model natural laminar flow nacelle has been conducted with favorable results. Both isolated and installed tests have been conducted in the 16-Foot Wind Tunnel at NASA Langley to assess the feasibility of natural laminar flow to reduce nacelle external friction drag. Laminar flow drag reduction was verified in the isolated nacelle testing by force balance data as well as momentum rake integration. The installed nacelle drag reduction was measured by force balance only. Acenaphthene was utilized as a flow visualization tool to indicate the axial extent of laminar flow on the nacelle during both isolated and installed testing. The flow visualization data confirmed the presence of a significant region of laminar flow on the nacelle forebody as was also deduced by the measured drag reductions.

879. HARRIS, A. E.; PALIWAL, K. C.: **Civil turbofan propulsion system integration studies using powered testing techniques at ARA, Bedford.**: AIAA PAPER 84-0593, Aerodynamic Testing Conference, 13th, San Diego, CA, March 5-7, 1984, Technical Papers (84A24176 09-09). New York, American Institute of Aeronautics and Astronautics, 1984, p. 74-98. 84A24184

A relatively comprehensive development test approach to civil turbofan engine/airframe integration is discussed in terms of model testing and wind tunnel facilities. Testing techniques for isolated inlet and nozzle components are briefly described and sample data are used to identify some important aspects of the integration of the engine and the nacelle/pylon. The aerodynamics of nacelle/pylon/wing is discussed and an integration test plan for identifying important installation and interference effects is defined. A Mach simulation tank for calibrating nacelle models is described which can identify aircraft drag increments of one third of one percent. An approach to assessing the influence of fan rpm-dependent sampling effects on the measured nozzle/duct pressures and temperatures and derived fan nozzle coefficients is presented in which the relationships between the 'true' and the 'measured' values of duct total pressures and temperatures are computed directly from the derived nozzle coefficients.

880. TINOCO, E. N.; CHEN, A. W.: **Transonic CFD applications to engine/airframe integration.** AIAA PAPER 84-0381 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 10 p. 84A18052

The application of transonic computational methods to the analysis of pylon wing-mounted engine/airframe configurations typical of subsonic transports is presented. The computational methods used include a three-dimensional isolated nacelle code based on a time-dependent Euler formulation; an axisymmetric explicit Navier-Stokes code for exhaust system analysis and plume modeling calibration; and a three-dimensional full-potential finite volume wing-body-strut-nacelle code. Comparisons of experimental and calculated pressure distributions on isolated nacelles and on wing-body-strut-nacelle configurations are presented. The agreement between computed results and test data is shown to be very good both in terms of trends and absolute levels.

881. CLARK, D. R.; MASKEW, B.; DVORAK, F. A.: **The application of a second generation low-order panel method -program 'Vsaero' - to powerplant installation studies.**: AIAA PAPER 84-0122 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 10 p. Research supported by the General Electric Co. 84A17895

Results from the application of a second generation low-order panel method to a number of powerplant installations are presented. The method, which retains the advantages of ease of use and low operating cost of earlier panel methods while retaining the aerodynamic modelling rigor of higher-order methods was used to predict the flow in and around typical nacelles and aircraft for a wide range of conditions. The ability of the second generation low-order analysis to calculate internal flows without the leakage problems associated with earlier programs is demonstrated and correlation between calculated and measured surface pressures and flow behavior, including predicting streamlines and locating regions of separated flow, is presented.

882. KUTNEY, J. T.: **Advancements in the aerodynamic integration of engine and airframe systems for subsonic aircraft.** International Journal of Turbo and Jet-Engines, vol. 1, no. 1, 1983-1984, p. 29-43. 1984. 84A31316

A comparative study is conducted for the relative aerodynamic advantages or penalties of subsonic aircraft wing- and fuselage-mounted nacelle installations. Both short duct and long duct nacelles are considered, and theoretical treatments for the phenomenon of interference drag are compared with wind tunnel data which illustrate the importance of such diagnostic test results in the isolation of the integration problem and the reduction of installed drag. Attention is given to parasitic drag component breakdowns for engine core cowl, pylon scrubbing, and plug scrubbing, as well as external friction and pressure drag, together with the phenomena of nacelle-fuselage and nacelle-wing channel flow areas and interference drag.

883. ERDOS, J. I.; RAY, R.; MANDEL, M.: **Aeromechanical applications of favorable supersonic interference. Volume 3: Performance of a Mach 3 aircraft concept based on nacelle-wing interference (U)** AD-C032942L GASL-TR-266 AFWAL-TR-82-3020-VOL-3 1983. 84X72794 US GOV AGENCIES

884. CAPONE, F. J.; REUBUSH, D. E.: **Effects of varying podded nacelle-nozzle installations on transonic aeropropulsive characteristics of a supersonic fighter aircraft.** NASA-TP-2120 L-15525 NAS 1.60:2120 1983. 83N26821

The aeropropulsive characteristics of an advanced twin engine fighter designed for supersonic cruise was investigated in the 16 foot Transonic Tunnel. The performance characteristics of advanced nonaxisymmetric nozzles installed in various nacelle locations, the effects of thrust induced forces on overall aircraft aerodynamics, the trim characteristics, and the thrust reverser performance were evaluated. The major model variables included nozzle power setting; nozzle duct aspect ratio; forward, mid, and aft nacelle axial locations; inboard and outboard underwing nacelle locations; and underwing and overwing nacelle locations. Thrust vectoring exhaust nozzle configurations included a wedge nozzle, a two dimensional convergent divergent nozzle, and a single expansion ramp nozzle, each with deflection angles up to 30 deg. In addition to the nonaxisymmetric nozzles, an axisymmetric nozzle installation was also tested. The use of a canard for trim was also assessed.

885. CHEN, A. W.; TINOCO, E. N.: **PAN AIR applications to aero-propulsion integration.** AIAA PAPER 83-1368 AIAA, SAE, and ASME, Joint Propulsion Conference, 19th, Seattle, WA, June 27-29, 1983. 11 p. 83A36364

Several diverse applications of the PAN AIR system to aeropropulsion problems are presented in order to demonstrate the versatility of the method. These illustrative examples involve the coupling of PAN AIR to a three-dimensional boundary layer analysis for obtaining iterative solutions, and include a study of the internal flow losses through a calibration nozzle, the calculation of surface pressures about an isolated nacelle, and the modeling of exhaust flows.

886. WAGGONER, E. G.: **Computational analysis for an advanced transport configuration with engine nacelle.** AIAA PAPER 83-1851 American Institute of Aeronautics and Astronautics, Applied Aerodynamics Conference, Danvers, MA, July 13-15, 1983. 13 p. 83A38679

A small-disturbance transonic analysis code is used to calculate the flow-field effects of adding an engine nacelle to a wing/body configuration. Analyses are performed on an advanced transport configuration with and without engine nacelles. Two nacelle shapes are analyzed and the effects of the nacelle installation on pressure distributions are compared with experimental results obtained by shifting the nacelle longitudinally and vertically relative to the wing. Effects of varying the nacelle installation yaw angle are also analyzed and compared with experimental data. These comparisons show that the analysis code is adequately sensitive to variations in nacelle shape, longitudinal and vertical location beneath the wing, and the nacelle installation yaw angle. Results indicate that the code can be used as an effective guide during the design process.

887. VAHL, W. A.: **Experimental determination of flow-interference effects of wing-mounted, two-dimensional, full-capture propulsion nacelles in close proximity to a vehicle body at a Mach number of 6.**: NASA-TM-83287 L-15209 NAS 1.15:83287 May 1982 82N25217

Experimental tests have been conducted to determine possible aerodynamic interference effects due to the lateral positioning of two dimensional propulsion nacelles mounted on a wing surface in close proximity to a vehicle body. The tests were conducted at a Mach number of 6 and a Reynolds number 7 million per foot. The angle of attack range for force tests was -9 deg to 9 deg. The model configurations consisted of combinations of rectangular and trapezoidal cross section bodies with a wing swept 65 and a rectangular planform wing. A pair of two dimensional, flow through propulsion nacelles simulated full capture inlet operation.

888. PAGE, G. S.; CUNNINGHAM, E. J.; WELGE, H. R.: **Supersonic aerodynamic wind tunnel test results of an advanced 2.2 Mach cruise transport configuration.** NASA-CR-165933 NAS 1.26:165933 MDC-J9408 1982. 82X10251 US GOV AGENCIES AND CONTRACTORS

A wind tunnel test of a McDonnell Douglas Mach 2.2 advanced supersonic transport configuration was conducted in the NASA-Langley 4x4 foot supersonic wind tunnel. The purposes of the test were to verify refined aerodynamic analysis procedures, and to verify the performance of the refined wing design, designated wing W4. Comparisons of experimental data with theoretical estimates show good agreement over the test Mach number range of 1.8 to 2.86 Mach. Performance of the refined W4 wing configuration show a 0.92 improvement in L/D from the previous test configuration, for a trimmed, full scale L/D of 9.75 at 2.2 Mach. The configuration also achieves a favorable nacelle interference for the wing/nacelle integration technique

used. The experimental data show the W4wing configuration does not present any lateral-directional stability problems at cruise. Data analysis indicates the W4 wing configuration did not produce the predicted pitching moment increment due to nacelle addition. A further L/D improvement is available by recambering the wing for the measured nacelle pitching moment.

889. YETTER, J. A.; EVELYN, G. B.; MERCER, C.: **Transonic wind tunnel test of a supersonic nozzle installation.** AIAA PAPER 82-1045 AIAA, SAE, and ASME, Joint Propulsion Conference, 18th, Cleveland, OH, June 21-23, 1982, AIAA 14 p. 1982. 82A37677

The design of the propulsion system installation affects strongly the total drag and overall performance of an aircraft, and the concept, placement, and integration details of the exhaust nozzle are major considerations in the configuration definition. As part of the NASA Supersonic Cruise Research (SCR) program, a wind tunnel test program has been conducted to investigate exhaust nozzle-airframe interactions at transonic speeds. First phase testing is to establish guidelines for follow-on testing. A summary is provided of the results of first phase testing, taking into account the test approach, the effect of nozzle closure on aircraft aerodynamic characteristics, nozzle installation effects and nacelle interference drag, and an analytical study of the effects of nozzle closure on the aircraft.

890. YETTER, J. A.; EVELYN, G. B.: **Nozzle installation effects for supersonic cruise configurations.** NASA-CR-165835 NAS 1.26:165835 1982. 82X10252
US GOV AGENCIES AND CONTRACTORS

A wind tunnel test was conducted to evaluate exhaust nozzle airframe interactions at transonic speeds, for a representative supersonic cruise vehicle with an underwing nacelle installation. The purpose of the test was threefold: (1) to establish and validate a test approach from which the nozzle performance, nozzle drag, power sensitive boattail effects, and nozzle airframe interactions could be evaluated; (2) determine the magnitude of the nozzle installation effects for use in related NASA-Supersonic Cruise Technology system studies; and (3) provide a data base for validation of analytical codes. The test results indicated that the test approach does permit evaluation of nozzle airframe interactions and the performance assessment of candidate nozzle concepts for development of low drag supersonic exhaust system installations. Favorable installation effects were found to be significant at high subsonic cruise Mach Numbers. A three dimensional linearized potential flow analysis provided qualitative results that aided in interpretation of the test data.

891. VANENGELEN, J. A. J.; MUNNIKSMA, B.; ELSENAAR, A.: **Evaluation of an experimental technique to investigate the effects of the engine position on engine/pylon/wing interference.**: NLR-MP-81020-U April 1981 82N28262

Free flow and blown nacelle wind tunnel testing of engine-airframe integration are compared, and the magnitude of the parasitic interference of an additional strut and engine inlet fairing is examined. A semispan model, typical of a transport aircraft with a supercritical wing was tested. A 3/4 fan cowl high bypass engine was located at six positions underneath the wing. Measurements included pressure and balance force. It is shown that while accurate simulation of engine nozzle geometry is of prime importance, tests on free flow nacelles are useful for selecting engine position. Interference forces derived from pressure integration are only useful for determining trends in interference effects for flexible initial tests.

892. EWALD, B.; SMYTH, R.: **The role and implementation of different nacelle/engine simulation concepts for wind-tunnel testing in research and development work on transport aircraft.** In AGARD Aerodyn. of Power Plant Installation, 35 p (See 82N13065 04-01) 1981. 82N13086

Different experimental methods and their specific roles in various stages of research and development were investigated. The main problem is the simulation and calibration of the propulsion system. Different simulation methods are: flow through nacelles, powered nacelles (blowing, turbine powered simulators (TPS), ejector powered), inlet models. The TPS represent the most advanced simulation of the high bypass ratio engine in model scale. A large part of the wind tunnel tests still have to rely upon flow through nacelles. A novel flow through nacelle with a variable plug is presented. It is shown that the combination of flow through nacelles and TPS can be efficiently used in the wind tunnel investigation of propulsion system effects for transport aircraft.

893. KLEVENHUSEN, K. D.; JAKOB, H.; STRUCK, H.: **Calculation of wing-body-nacelle interference in subsonic and transonic potential flow.** In AGARD Aerodyn. in Power Plant Installation 8 p (SEE 82N13065 04-01) 1981. 82N13095

A calculation method especially for transport aircraft wing design with consideration of wing/body or engine/airframe interference was developed. A hybrid method, consisting of a combination of panel method and finite difference method, is an improvement of a well proved analogy method. The panel method is of higher order using linear source and doublet distributions. The transonic flow region is removed from the entire flow field and the panel method is used for calculating boundary values for the subsequent finite difference method. The finite difference method solves the full potential equation in streamline coordinates.

894. JOHNSON, P.; EVELYN, G.: **Installed nozzle test program**. In its Advan. Concept Studies for Supersonic Vehicles, 18 p (See 82X10002 01-01) 1981. 82X10013 US GOV AGENCIES AND CONTRACTORS

Availability of suitable model hardware, test facilities and current testing practices were reviewed. Previous isolated nozzle test results were studied to determine an appropriate generic supersonic cruise research nozzle design for the installed nozzle test program. A test plan,comprising a summary of the proposed test configurations, test conditions,force bookkeeping techniques, and data reduction requirements was formulated and refined. Nacelle and nozzle model hardware were designed and fabricated. Testing was completed and preliminary analysis initiated. Available computer codes, applicable to the analysis of the test configurations, were surveyed, and a theoretical analysis was initiated. This analysis, made to predict installed nozzle flow field, was limited to assessing the isolated nacelle boattail region. Several simplified representations of the exhaust plume were examined and compared with prior NASA test data.

895. KULFAN, R. M.; SIGALLA, A.: **Airframe-propulsion system aerodynamic interference predictions at high transonic Mach numbers including off-design engine airflow effects**. In AGARD Aerodyn. of Power Plant Installation 23 p (SEE 82N13065 04-01) 1981. 82N13098

The transonic speed regime for airplanes at conditions where inlet spillage takes place is discussed. A wind tunnel test program to evaluate aerodynamic performance penalties associated with propulsion system installation and operation at subsonic through low supersonic speeds was conducted. The accuracy of analytic methods for predicting transonic engine airframe interference effects was assessed. Study variables included Mach number, angle of attack, relative nacelle location, and nacelle mass flow ratio. Results include test theory comparisons of forces as well as induced pressure fields. Prediction capability of induced shock wave strength and locations is assessed. It was found that large interference forces due to engine location and flow spillage occur at transonic speeds, that theory explains these effects; and that theory can predict quantitatively these effects.

896. BLISSEL, W.; KULFAN, R.: **Analysis of transonic nacelle interference.** In its Advan. Concept Studies for Supersonic Vehicles 43 p (SEE 82X10002 01-01) 1981. 82X10004 US GOV AGENCIES AND CONTRACTORS

Studies to improve correlations between theoretical predictions and test results assessing shock-spillage interference effects on nacelle-airframe interference are summarized. Effects associated with the aerodynamic efficiency of the propulsion system's installation and operation at subsonic through supersonic speeds are considered. Specific areas discussed are: (1) sensitivity of the capture streamtube shape on predicted effects of reduced mass-flow on nacelle-airframe interference, (2) alternative procedures for calculating interference effects using streamtube shapes predicted by flow analysis methods, and (3) comparisons of predicted oblique-shock and normal-shock spillage effects on nacelle-airframe interference. Results of flow analyses imply that oblique-shock spillage interference effects are milder than normal-shock spillage interference effects.

897. HOELEN, F. J.: **B-1 Inlet and Nozzle Flight Performance Determination program**. AIAA PAPER 81-1852 American Institute of Aeronautics and Astronautics, Atmospheric Flight Mechanics Conference, Albuquerque, NM, Aug. 19-21, 1981, 7 p., USAF-sponsored research. 82A13981

The B-1 Inlet and Nozzle Flight Performance Determination program was part of an overall USAF research program for the improvement of installed inlet and nozzle performance prediction techniques. Data were acquired by adding external surface pressure instrumentation in the region of the left inlet and aft nacelle of a B-1 aircraft by and instrumenting three B-1 wind tunnel models like the aircraft and conducting wind tunnel tests at conditions matching the flight-test points. Wind tunnel and flight-test data were correlated in the transonic range. Comparisons of model and aircraft inlet and aft nacelle drags derived from pressure area integration are presented. Results show that the 0.06 scale model aft nacelle drags are three to eleven drag counts higher than those of the aircraft with approximately

parallel data trends. The inlet model drags were also higher than those of the aircraft, and data trends were again parallel. The 0.07 scale inlet model ramp drag was three drag counts higher than aircraft values, while cowl drags were as much as eight counts higher in the subsonic portion of the transonic range.

898. KULFAN, R. M.: **Prediction of nacelle aerodynamic interference effects at low supersonic Mach numbers**. In NASA Langley Res. Center Supersonic Cruise Res. 1979, Pt. 1, p 171-203 (See 81N17981 09-01) March 1980 81N17988

The accuracy of analytical predictions of nacelle aerodynamic interference effects at low supersonic speeds are studied by means of test versus theory comparisons. Comparisons shown include: (1) isolated wing body lift, drag, and pitching moments; (2) isolated nacelle drag and pressure distributions; (3) nacelle interference shock wave patterns and pressure distributions on the wing lower surface; (4) nacelle interference effects on wing body lift, drag, and pitching moments; and (5) total installed nacelle interference effects on lift, drag, and pitching moment. The comparisons also illustrate effects of nacelle location, nacelle spillage,angle of attack, and Mach numbers on the aerodynamic interference. The initial results seem to indicate that the methods can satisfactorily predict lift, drag, pitching moment, and pressure distributions of installed engine nacelles at low supersonic Mach numbers with mass flow ratios from 0.7 to 1.0 for configurations typical of efficient supersonic cruise airplanes.

899. MERCER, C. E.; CARSON, G. T., JR.: **Transonic aerodynamic characteristics of a supersonic cruise aircraft research model with the engines suspended above the wing**. NASA-TM-80145 L-12811 1979. 80N12997

The influence of upper-surface nacelle exhaust flow on the aerodynamic characteristics of a supersonic cruise aircraft research configuration was investigated in a 16 foot transonic tunnel over a range of Mach numbers from 0.60 to 1.20. The arrow-wing transport configuration with engines suspended over the wing was tested at angles of attack from -4 deg to 6 deg and jet total pressure ratios from 1 to approximately 13. Wing-tip leading edge flap deflections of -10 deg to 10 deg were tested with the wing-body configuration. Various nacelle locations (chordwise, spanwise, and vertical) were tested over the ranges of Mach numbers, angles of attack, and jet total-pressure ratios. The results show that reflecting the wing-tip leading edge flap from 0 deg to -10 deg increased the maximum lift-drag ratio by 1.0 at subsonic speeds. Jet exhaust interference effects were negligible.

900. KOWALSKI, E. J.: **Computer code for estimating installed performance of aircraft gas turbine engines.** Volume 1: Final report.: NASA-CR-159691 D180-25481-1-VOL-1 1979. 80N13043

A computerized method which utilizes the engine performance data is described. The method estimates the installed performance of aircraft gas turbine engines. This installation includes: engine weight and dimensions,inlet and nozzle internal performance and drag, inlet and nacelle weight, and nacelle drag.

901. RICHEY, G. K.; BOWERS, D. L.; KOSTIN, L. C.; PRICE, E. A., JR. **Wind Tunnel/Flight Test Correlation Program on the B-1 nacelle afterbody/nozzle at transonic conditions.** AIAA PAPER 78-989 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 8 p. 1978. 78A48469

The B-1 Wind Tunnel/Flight Test Correlation Program had the objective to investigate the B-1 propulsion nacelle flow field differences between wind tunnel and flight test and determine the sources of these differences. The wind tunnel and flight tests of the program are discussed and a description is presented of the corresponding nacelle afterbody/nozzle instrumentation. A 0.06 scale B-1 nozzle afterbody model was used as wind tunnel model. Flight data were obtained during the B-1 No. 2 structural test flight development program. The test results obtained in the investigations provide a good data base for the study of the flow characteristics in transonic flow and differences/similarities between wind tunnel and flight for an exhaust nozzle/aftbody system which is closely integrated with the wing and fuselage.

902. WILSON, J. R.; BENSON, J. L.: **Propulsion system airframe integration studies - Advanced supersonic transport**. AIAA PAPER 78-1053 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 7 p. 1978. 78A48488

One of the objectives of the considered integration studies is related to the identification of engine/airframe configurations which offer the best performance potential within environmental constraints. Other objectives include

the identification of engine cycle and geometry improvements, the development of practical preliminary designs of most promising configurations, and the identification of test and development program requirements. The variables examined in the study are related to the engine nacelle location, the inlet configuration, the engine cycle/configuration, engine-inlet airflow match, engine thrust schedule, and engine accessory location. Attention is given to propulsion system configurations, tradeoff studies, engine-inlet matching studies, aspects of nacelle design integration, and engine operational procedures.

903. WALKLEY, K. B.: **A comparison of the theoretical aerodynamic characteristics of the .015 scale Douglas Mach 2.2 advanced supersonic cruise transport model with wind tunnel data.** NASA-CR-158897 1978. 80X10001 US GOV AGENCIES AND CONTRACTORS

The theoretical aerodynamic characteristics of the .015 scale Douglas advanced supersonic cruise transport model at Mach numbers from 0.5 to 2.4are presented. Comparisons of these results with measured wind tunnel data are also presented. Aerodynamic data presented include lift, drag, and pitching moment coefficients as well as lift-to-drag ratio characteristics. Both wing-body and wing-body-nacelle configurations were analyzed. The aerodynamic methods employed in the analysis are discussed.

904. WILSON, J. R.; BENSON, J. L.: **Propulsion system airframe integration studies - Advanced supersonic transport.** AIAA PAPER 78-1053 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 7 p. 1978. 78A48488

One of the objectives of the considered integration studies is related to the identification of engine/airframe configurations which offer the best performance potential within environmental constraints. Other objectives include the identification of engine cycle and geometry improvements, the development of practical preliminary designs of most promising configurations, and the identification of test and development program requirements. The variables examined in the study are related to the engine nacelle location, the inlet configuration, the engine cycle/configuration, engine-inlet airflow match, engine thrust schedule, and engine accessory location. Attention is given to propulsion system configurations, tradeoff studies, engine-inlet matching studies, aspects of nacelle design integration, and engine operational procedures.

905. RADKEY, R. L.; WELGE, H. R.; FELIX, J. E. **Aerodynamic characteristics of a Mach 2.2 advanced supersonic cruise aircraft configuration at Mach numbers from 0.5 to 2.4.** NASA-CR-145094 MDC-J4558 1977. 77X10013 US GOV AGENCIES AND CONTRACTORS

Wind tunnel tests were conducted on an advanced supersonic cruise aircraft model. Numerous technology problems associated with the design and analysis of supersonic cruise aircraft were explored to create a Mach 2.2 design information data base. The test addressed the validity of design and analysis methods as applied to arrow wing configurations, problems of wing reflexing to achieve beneficial wing-nacelle interference, and the possibility of using an external compression inlet rather than a mixed compression inlet at Mach 2.2. Configuration longitudinal and lateral-directional aerodynamic characteristics were determined, and pressure (247 ports) were taken simultaneously with the force data. Tuft and schlieren pictures were also taken.

906. WELGE, H. R.; RADKEY, R. L.; HENNE, P. A.: **Nacelle aerodynamic design and integration study on a Mach 2.2 supersonic cruise aircraft.** AIAA PAPER 76-757 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 12th, Palo Alto, Calif., July 26-29, 1976, AIAA 12 p. 1976. 76A42436

Results of a propulsion system integration study performed on a Mach 2.2 advanced supersonic cruise aircraft are discussed. Numerous inlet-nacelle combinations were examined in a preliminary screening study. Promising configurations were evaluated in a nacelle installation study in which structural weight and installed wave drag were traded leading to the selection of an axisymmetric single-engine pod installation as the most promising configuration. A detailed nacelle shape study was conducted, and a wing reflex was designed. A wind-tunnel test of the refined nacelle with both mixed and external compression inlets was conducted with the nacelles installed on both a refined baseline wing and a reflexed wing. Good agreement was observed between calculated and experimental increments in induced drag due to nacelle installation.

907. BENSON, J. L.; SEDGWICK, T. A.; WRIGHT, B. R.: **Supersonic cruise vehicle propulsion system integration studies.** AIAA PAPER 76-756 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 12th, Palo Alto, Calif., July 26-29, 1976, AIAA 10 p. 1976. 76A42435

The performance and systems integration aspects of a unique engine installation for a supersonic cruise vehicle, identified during an engine location study, are discussed. This installation consists of four separate engine nacelles - two located under the wing and two located over the wing at the same spanwise positions. This nacelle arrangement, while having some propulsion system performance and weight penalties relative to a more conventional configuration employing four underwing nacelles, offers improved vehicle mission performance because of reduced noise, improved low speed lift characteristics and reduced tail size. Propulsion system performance comparisons, integration studies and noise and mission performance results are presented showing that the over/under engine nacelle arrangement is an attractive supersonic cruise vehicle propulsion system configuration and worthy of additional study.

908. WITTMANN, M.: **Investigation of the mutual interference of wing/engine combinations.**: ESA-TT-217 DLR-FB-74-32 Dec. 1975 76N24184

The mutual interference between wing and engine nacelle is significant since aircraft engines are often arranged either above or below the wing. For theoretical calculations the wing is represented by a flat plate and the engine nacelle by a cylinder composed of source and vortex singularities. The normal velocity components induced on the wing by the nacelle are simulated by additional singularities on the wing in order to obtain a first approximation of the modified pressure distribution. Experimental results are represented for nine wing/nacelle combinations and three angles of attack. Three different intake blockages are also considered. For several cases the theoretical and experimental results are compared.

909. DELETED ABSTRACT

910. HAAGENSON, W. R.; RANDALL, L. M.: **Inlet development for the B-1 strategic bomber**. AIAA PAPER 74-1064 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 10th, San Diego, Calif., Oct. 21-23, 1974, AIAA 9 p. 1974. 75A10258

The B-1 inlet was originally a mixed compression design, but later changed to an external compression inlet (ECI). All major problems encountered in adapting the ECI to the B-1 were solved during the first wind tunnel development test. Aerodynamic characteristics of the inlet and, particularly, the characteristics of certain inlet control parameters are associated with the underwing location of the nacelle. Inlet distortion and inlet/engine compatibility have been carefully audited throughout the B-1 program. A demonstration of inlet/engine compatibility before first flight was provided by wind tunnel tests of a full-scale inlet/engine model at Arnold Engineering Development Center.

911. COOMBE, T. W.; GOLDSMITH, H. A.; MORRISS, D. P.: **Aerodynamic/structural interactions in the design of the Concorde nacelle.**: Association Aeronautique et Astronautique de France and Union Syndicale des Industries Aeronautiques et Spatiales, Congres International Aeronautique, 11th, Ecole Nationale Superieure de Techniques Avancees, Paris, France, May 21-23, 1973, Paper. 36 p. 74A25364

This paper examines the overall design of the Concorde nacelle from the point of view of the interaction of aerodynamic and structural requirements. It is shown that in general the influence of aerodynamics has been dominant, with the structure having to conform to the aerodynamic requirements as efficiently as possible. However, in some areas structural and weight considerations have played a major part.

912. BONNER, E.; ROE, M. H.; TYSON, R. M.; MAIRS, R. Y. : **Influence of propulsion system size, shape, and location on supersonic aircraft design**. NASA-CR-132544 1974. 75N14747

The effects of various propulsion system parameters on the characteristics of a supersonic transport were investigated. The effects of arbitrarily scaling engine size on wave drag, friction drag, drag-due-to-lift, wing sizing, airplane balance, and airplane weight were studied. These evaluations were made for two families of nacelle shapes, resulting from typical turbojet and turbofan installations. Also examined were effects of nacelle location, and the wing camber plane deformations required to cancel the nacelle interference pressure field at cruise Mach number (2.7 M) were determined. The most drag-sensitive parameter is found to be nacelle shape. Similarly, wing deformation requirements are found to be primarily affected by nacelle shape. Effects of engine size variations are noted primarily in airplane gross weight.

913. BENCZE, D. P.: **Nacelle-airframe interference at low supersonic Mach numbers.** AIAA PAPER 72-1113 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Specialist Conference, 8th, New Orleans, La., Nov. 29-Dec. 1, 1972, AIAA 11 p. 1972. 73A13428

The aerodynamic interference between the propulsion system and airframe for a low supersonic transport with wing-mounted nacelles is examined. Both a flowfield analysis and the equivalent body approach were used to predict the interference lift, drag, and pitching moment as functions of nacelle size, shape, and position. The results indicate that the interference lift and pitching moment, as well as drag, must be included in the analysis to properly assess the interference effects. In addition, the performance of the basic wing was found to play an important role in determining the effectiveness of the interference lift in reducing the net installation drag. Based on a conservative prediction, the interference effects can reduce the installed propulsion system drag to 40% of the isolated drag of the nacelles. Furthermore, including the interference effects in the optimization of the engine cycle from a thermodynamic and weight standpoint can result in a considerable reduction in the net propulsion system weight fraction (fuel plus engines) while increasing the optimum engine bypass ratio of a typical transport vehicle.

914. BENCZE, D. P.: **Experimental evaluation of nacelle-airframe interference forces and pressures at Mach numbers of 0.9 to 1.4.** NASA-TM-X-3321 A-6344 1977. 77N20028

Detailed interference force-and-pressure data were obtained on a representative supersonic transport wing-body-nacelle combination at Mach numbers of 0.9 to 1.4. The basic model consisted of a delta wing-body aerodynamic model with a length of 158.0 cm (62.2 in.) and a wingspan of 103.6 cm (40.8 in.) and four independently supported nacelles positioned beneath the model. The experimental program was conducted in the Ames 11- by 11-Foot Wind Tunnel at a constant unit Reynolds number. The primary variables examined included Mach number, angle of attack, nacelle position, and nacelle mass-flow ratio. Under the most favorable conditions, the net interference drag was equal to 50 percent the drag of four isolated nacelles at M = 1.4, 75 percent at M = 1.15, and 144 percent at M = 0.90. The overall interference effects were found to be rather constant over the operating angle-of-attack range of the configuration. The effects of mass-flow ratio on the interference pressure distributions were limited to the lip region of the nacelle and the local wing surface in the immediate vicinity of the nacelle lip. The net change in the measured interference forces resulting from variations in the nacelle mass-flow ratio were found to be quite small.

915. BENCZE, D. P.: **Wind tunnel investigation of nacelle-airframe interference at Mach numbers of 0.9 to 1.4 - pressure data, volume 1.** NASA-TM-X-73149 A-4982-VOL-1 1976. 76N26146

Detailed interference force and pressure data were obtained on a representative wing-body nacelle combination at Mach numbers of 0.9 to 1.4. The model consisted of a delta wing-body aerodynamic force model with four independently supported nacelles located beneath the wing-body combination. The model was mounted on a six component force balance, and the left hand wing was pressure instrumented. Each of the two right hand nacelles was mounted on a six component force balance housed in the thickness of the nacelle, while each of the left hand nacelles was pressure instrumented. The primary variables examined included Mach number, angle of attack, nacelle position, and nacelle mass flow ratio. Nacelle axial location, relative to both the wing-body combination and to each other, was the most important variable in determining the net interference among the components.

916. BENCZE, D. P.: **Wind tunnel investigation of Nacelle-Airframe interference at Mach numbers of 0.9 to 1.4-pressure data,volume 2.** NASA-TM-X-73088 A-4982 1976. 76N25144

Detailed interference force and pressure data were obtained on a representative wing-body nacelle combination at Mach numbers of 0.9 to 1.4. The model consisted of a delta wing-body aerodynamic force model with four independently supported nacelles located beneath the wing-body combination. The primary variables examined included Mach number, angle of attack, nacelle position, and nacelle mass flow ratio. Four different configurations were tested to identify various interference forces and pressures on each component; these included tests of the isolated nacelle,the isolated wing-body combination, the four nacelles as a unit, and the total wing-body-nacelle combination. Nacelle axial location, relative to both the wing-body combination and to each other, was the most important variable in determining the net interference among the components. The overall interference effects were found to be essentially constant over the operating angle-of-attack range of the configuration, and nearly independent of nacelle mass flow ratio.

917. BENCZE, D. P.: **Wind tunnel investigation of Nacelle-Airframe interference at Mach numbers of 0.9 to 1.4-force data.** NASA-TM-X-62489 A-4982 1976. 76N25143

Detailed interference force and pressure data were obtained on a representative wing-body-nacelle combination at Mach numbers of 0.9 to 1.4. The model consisted of a delta wing-body aerodynamic force model with four independently supported nacelles located beneath the wing-body combination. The model was mounted on a six-component force balance, and the left-hand wing was pressure-instrumented. Each of the two right-hand nacelles was mounted on a six-component force balance housed in the thickness of the nacelle, while each of the left-hand nacelles was pressure-instrumented. The primary variables examined included Mach number, angle of attack, nacelle position, and nacelle mass-flow ratio. Four different configurations were tested to identify various interference forces and pressures on each component; these included tests of the isolated nacelle, the isolated wing-body combination, the four nacelles as a unit, and the total wing-body-nacelle combination. Nacelle axial location, relative to both the wing-body combination and to each other, was the most important variable in determining the net interference among the components.

918. MIKKELSON, D.: **Propulsion airframe integration.** In Kansas Univ. Proc. of the NASA, Ind., Univ., Gen. Aviation Drag Reduction Workshop, p 387-402 (See 76N10997 02-01) 1975. 76N11026

Wind tunnel simulation tests are reported that utilize a 20 inch powered nacelle for airframe integration studies. Considered are: effects of boattail positioning, nacelle size, aft fuselage drag, over-the-wing half span model installation, and turboprop and ducted fan configurations.

919. MUNNIKSMA, B.; JAARSMA, F.: Jet interference of a podded engine installation at cruise conditions. In AGARD Airframe/Propulsion Interference 16 p (SEE 75N23485 15-02). 1975. 75N23490

The results of an experimental wind tunnel test program on the wing-pylon-bypass engine combination of the Airbus A 300 B airplane are presented. Only aerodynamic interference due to the engine jet was considered. For determining the interference drag due to the engine jet as well as to have the possibility to extrapolate the test results from model reference conditions to full scale a test scheme was developed. To prove the validity of the assumptions of this scheme several intermediate steps were made. As the engine jet-airframe interference is mutual, also effects of the external flow on the internal engine nozzle flow causing engine shifting has to be considered. In order to estimate the magnitude of this influence of the external flow field a two-dimensional model of the fan nozzle has been tested using an optical technique. From these tests the specific features of the fan nozzle flow field ranging from subcritical via supercritical to choked conditions are described.

920. BENCZE, D. P.: **Nacelle-airframe interference at low supersonic Mach numbers.**: AIAA PAPER 72-1113 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Specialist Conference, 8th, New Orleans, La., Nov. 29-Dec. 1, 1972, AIAA 11 p. 73A13428

The aerodynamic interference between the propulsion system and airframe for a low supersonic transport with wing-mounted nacelles is examined. Both a flowfield analysis and the equivalent body approach were used to predict the interference lift, drag, and pitching moment as functions of nacelle size, shape, and position. The results indicate that the interference lift and pitching moment, as well as drag, must be included in the analysis to properly assess the interference effects. In addition, the performance of the basic wing was found to play an important role in determining the effectiveness of the interference lift in reducing the net installation drag. Based on a conservative prediction, the interference effects can reduce the installed propulsion system drag to 40% of the isolated drag of the nacelles. Furthermore, including the interference effects in the optimization of the engine cycle from a thermodynamic and weight standpoint can result in a considerable reduction in the net propulsion system weight fraction (fuel plus engines) while increasing the optimum engine bypass ratio of a typical transport vehicle.

921. JOHNSON, D. F.; MITCHELL, G. A.: **Experimental investigation of the interaction of a nacelle-mounted supersonic propulsion system with a wing boundary layer.** NASA-TM-X-2184 E-59831971. 71N19853

922. FLECHNER, S. G.: **Preliminary wind-tunnel investigation of the effects of engine nacelles on a transport configuration with high lift/drag ratios to a Mach number of 1.00.** NASA-TM-82312 LWP-939 71/02/16 81N19099

Wind tunnel tests to determine the effect of engine nacelles added to a low wing fuselage vertical tail configuration utilizing the NASA supercritical airfoil and

a refined area ruled fuselage are discussed. The engine arrangement consisted of two aft fuselage, side mounted flow through nacelles and a solid body of revolution mounted above the fuselage in a manner similar to the Boeing 727. A preliminary analysis of the wind tunnel data shows that favorable interference drag can be obtained with the proper longitudinal locations of the nacelles, by canting the nacelle inlets, and by cusping the rearward region of the nacelle.

923. HEAD, V. L.; MIKKELSON, D. C.: **Flight investigation of airframe installation effects on a variable flap ejector nozzle of an underwing engine nacelle at Mach numbers from 0.5 to 1.3.**: NASA-TM-X-2010 E-5467 1970 70N26569

This report contains information on airframes, exhaust nozzles, nacelles, aerodynamic drag, aircraft control, ejectors, engine inlets, control surfaces, installation, wing-fuselage stores, and flaps.

924. MACK, R. J.: **A numerical method for evaluation and utilization of supersonic nacelle-wing interference.** NASA-TN-D-5057 1969. 69N19641

925. PATTERSON, J. C., JR.: **Wind tunnel studies of nacelle interference drag at high subsonic speeds including the effect of powered jets.** In its Conf. on Aircraft Aerodynamics p 259-270 (SEE 75N71754 05-98) 1966. 75N71772

9.0 EXTERNAL DISTURBANCES TO THE PROPULSION SYSTEM FLOWFIELD

9.1 STORES/PYLON EFFECTS

926. HEIM, E. ROLAND: **CFD wing/pylon/unfinned store mutual interference wind tunnel experiment. Volume 4: Wing data, ID's 66-175**: AD-B128344L AFATL-TR-88-134-VOL-4 Nov. 1988 89X71857 US GOV AGENCIES AND CONTRACTORS

927. CENKO, A.; MEYER, R.; TESSITORE, F.: **Further development of the influence function method for store aerodynamic analysis.** (AIAA, Aerospace Sciences Meeting, 21st, Reno, NV, Jan. 10-13, 1983, AIAA Paper 83-0266) Journal of Aircraft (ISSN 0021-8669), vol. 23, Aug. 1986, p. 656-661. Previously cited in issue 05, p. 584, Accession no.83A16622. 1986. 87A10523

This report contains information on aerodynamic interference, computational fluid dynamics, external store separation, influence coefficient, stability derivatives, aerodynamic characteristics, supersonic speed, and wing-fuselage stores.

928. WILCOX, F. J., JR. : **Store carriage drag measurements of an advanced fighter aircraft at supersonic speeds.**: NASA-TP-2521 L-15894 NAS 1.60:2521 1985 86X10223 DOMESTIC

An investigation has been conducted in the Langley Unitary Plan Wind Tunnel to determine the zero-lift store-drag increment at Mach numbers 1.60, 1.80, and 2.16 of AIM-9L Sidewinder missiles and AIM-120A Advanced Medium-Range Air-to-Air Missiles (AMRAAM's) installed on an advanced fighter aircraft. The missiles were installed in pylon, tangent, and semisubmerged mounts and were mounted in various wing, wing-tip, fuselage,and combination wing-fuselage carriage configurations. Tabulated data are included along with far-field wave-drag analysis and data comparison with the predictions method of DATCOM/Hoerner (empirical method).

929. POISSON-QUINTON, P.: **Parasitic and interference drag prediction and reduction.** In AGARD Aircraft Drag Prediction and Reduction, 27 p (See 86N15266 06-02) July 1985 86N15272

Parasitic drag related to excrescences, leaks, etc., and to local flow separations, and interference drag related to wing/fuselage, propulsive nacelle/wing or fuselage, and external stores/wing or fuselage, etc., are discussed. Although a precise prediction of such drag terms is still difficult to obtain in wind-tunnel testing, a large number of typical trends are available to the designer to avoid too large penalties on transport or combat aircraft at the preliminary design stage; several examples are given to illustrate these trends, together with some optimization methods.

930. KEEN, K. S.: **Inexpensive calibrations for the influence function method using the interference distributed loads code.**: AIAA PAPER 85-0270 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 23rd, Reno, NV, Jan.

14-17, 1985. 5 p. USAF-supported research. 1985. 85A19623

Two engineering prediction methods for the calculation of store aerodynamic loads within the interference flow field of an aircraft have been integrated to produce a tool with capabilities beyond the range of either method individually. A reduction in computer cost of three-orders-of-magnitude has been realized in the theoretical determination of the influence response coefficient distributions of conventional store configurations. Additionally, nonlinear aerodynamic effects such as vortex downwash on the store afterbody were modeled. The integrated method has been incorporated into an interactive geometry modeling/input preparation system which allows a user with little or no familiarity with the related codes to derive the influence coefficient distributions with minimal effort. Predictions of store loads in an aircraft flow field using these influence coefficients have shown very good agreement with experimental data.

931. DESLANDES, R. : **The representation of aircraft-external store-interferences under supersonic conditions.**: DGLR PAPER 84-112 Deutsche Gesellschaft fuer Luft- und Raumfahrt, Jahrestagung, Hamburg, West Germany, Oct. 1-3, 1984. 23 p. In German. Oct. 1984 85A40328

The importance of supersonic missions for modern fighter aircraft increases continuously, and an aerodynamic integration of external stores becomes vital. Such stores can include fuel tanks and air-to-air missiles.An optimal design and the development of the involved components must be based on an accurate knowledge regarding the flow around the considered configuration. Interference effects arising in the case of the external store-aircraft configuration are related to the external flow around the aircraft with the existing shock fronts, detached shocks at the external store, embedded subsonic fields, and shock reflections between external store and aircraft. Attention is given to the aerodynamic and numerical problems, advantages of the zonal decomposition approach, the method employed for the solution of the obtained system of partial differential equations, the computational grid developed for the employment of the finite-volume procedure, and computational results which describe the interference effects. This study indicates an approach for quantifying the considered interferences.

932. HARRIS, A. E.; PALIWAL, K. C.: **Civil turbofan propulsion system integration studies using powered testing techniques at ARA, Bedford.**: AIAA PAPER 84-0593, Aerodynamic Testing Conference, 13th, San Diego, CA, March 5-7, 1984, Technical Papers (84A24176 09-09). New York, American Institute of Aeronautics and Astronautics, 1984, p. 74-98. 84A24184

A relatively comprehensive development test approach to civil turbofan engine/airframe integration is discussed in terms of model testing and wind tunnel facilities. Testing techniques for isolated inlet and nozzle components are briefly described and sample data are used to identify some important aspects of the integration of the engine and the nacelle/pylon. The aerodynamics of nacelle/pylon/wing is discussed and an integration test plan for identifying important installation and interference effects is defined. A Mach simulation tank for calibrating nacelle models is described which can identify aircraft drag increments of one third of one percent. An approach to assessing the influence of fan rpm-dependent sampling effects on the measured nozzle/duct pressures and temperatures and derived fan nozzle coefficients is presented in which the relationships between the 'true' and the 'measured' values of duct total pressures and temperatures are computed directly from the derived nozzle coefficients.

933. VAN DEN BROEK, G. J.: **Application of panel methods in external store load calculations**. Journal of Aircraft (ISSN 0021-8669), vol. 21, July 1984, p. 537-539. 84A37940

The effect of aircraft wind modelling on the external store loads is investigated by computing that effect for the external flow field generated by the wing. The application of the panelling/boundary condition method to the perturbation flow field below the wing is first considered; then, the effect of the wing panelling in the leading edge region, where the singularity distributions show large gradients, on the flow field is studied. Both lift and thickness effects are taken into account.

934. SORRELLS, R. B.; TOWNE, M. C.; ANDERSON, C. F.; TOLBERT, R. H.: **Effects of inlet spillage on store carriage loads and launch trajectories.**: AIAA PAPER 84-0615 American Institute of Aeronautics and Astronautics, Aerodynamic Testing Conference, 13th, San Diego, CA, Mar. 5-7, 1984. 4 p. 84A25731

Aircraft/store compatibility wind tunnel tests have been traditionally conducted without regard for the particular throttle-dependent inlet spillage condition which is simulated in the aircraft model. Tests were conducted in the AEDC 4-ft transonic wind tunnel (Aerodynamic Wind

Tunnel (4T)) on a twin-engined, horizontal-ramped inlet fighter aircraft configured with air-to-air missiles and with provisions for simulating both maximum and cruise inlet spillage. The results indicate that for the missile carried nearest to the inlet the carriage loads were as high as 100 percent larger for the maximum spillage condition than for the cruise spillage condition. Jettison trajectories calculated for this missile indicate that the ejection forces dominate the early portion of the trajectory, and no significant difference was seen between maximum and cruise spillage conditions.

935. CENKO, A.; MEYER, R.; TESSITORE, F.; DYER, R.; LIJEWSKI, L.: **Advances in methods for predicting store aerodynamic characteristics in proximity to an aircraft.**: AIAA PAPER 83-0266 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 21st, Reno, NV, Jan. 10-13, 1983, 10 p. 83A16622

The results of a wind tunnel test are presented which indicate that the Influence Function Method (IFM) technique can be used at subsonic/transonic speeds. A new calibration technique was applied to three stores: the Planar Wing Weapon, air-to-ground stores, and the GBU-15 cruciform wing store. These stores were tested in proximity to an F-15 model at the centerline and under the pylon. Data were obtained for Mach numbers from 0.6 to 1.2 at a tunnel until Reynolds number of 2.5 million per foot. The IFM method is shown to provide excellent predictions of side force and yawing moment, and may also be applicable to drag and rolling moment predictions. The technique's utility can be enhanced by employing theoretical methods for store calibration and aircraft flowfield determination.

936. PAN, N.-Q.; WANG, W.-F.; XU, S.-J.; HUANG, Z.-X.: **Finite difference computation of the aerodynamic interference of wing-pylon-store combinations at transonic speeds**. Computer Methods in Applied Mechanics and Engineering (ISSN 0045-7825), vol. 37, March 1983, p. 1-13. 84A16839

The present computational method for determining the aerodynamic interference at work in wing-pylon-store configurations is based on the mixed finite difference method introduced by Murman and Cole (1971), although its governing steady flow, transonic, small disturbance potential equation is derived without the assumption of small disturbances in the longitudinal direction. The boundary condition on the surface of the wing-pylon-store configuration is satisfied, together with the Kutta condition for the vortex sheets. The computer program which executes these calculations can produce all flow field requirements, including perturbation potential, downwash speed, sidewash speed, pressure distributions, and aerodynamic coefficients. The three examples to which the method is applied indicate its convergence and degree of agreement with wind tunnel test values.

937. HAINES, A. B.: **External stores interference**. In AGARD Spec. Course on Subsonic/Transonic Aerodyn. Interference for Aircraft, 20 p (See 84N12072 03-01) 1983 84N12083

External store installations are frequently a source of considerable adverse aerodynamic interference giving large increases in drag, reductions in usable lift and poor store release characteristics. This adverse interference can be greatly alleviated or even transformed into favorable interference. Some of the available evidence for a wide variety of arrangements is given. The nature of the interference, both adverse and favorable, is described, particular emphasis being placed on the major adverse interference in standard multiple carriers and in some underwing installations. The possible benefits of wing tip carriage and carefully arranged under fuselage arrays are noted. Throughout, stress is laid on the fact that dramatic improvements might be possible by adopting a radical approach to store carriage.

938. Average downwash at the tailplane at low angles of attack and subsonic speeds; Amendment A.: ESDU-80020-AMEND-A AERO-A.08.01.02 AERO-A.08.01.03 AERO-A.08.01.04 ISBN-0-85679-303-5 ISSN-0141-397X Oct. 1981 83N32747

This Data Item is available as part of the ESDU Sub-series on Aerodynamics. A simple method is described for estimating the average downwash angle at the tailplane for subsonic speeds and low angles of attack where the lift, pitching moment and downwash characteristics are linear, i.e. where the flow is wholly attached. The method, which is semi-empirical, is a first order one allowing for the major effects of wing planform, body, wing-body interference and tailplane height. Moderate amounts of wing twist are also catered for. The method applies only to wing-body-tail combinations although some assessment of the effect of rear-fuselage mounted nacelles is given.

939. LEE, P.: **Drag measurements at transonic speeds of individual stores within multiple store arrangements.**: RAE-TM-AERO-1915 BR82139 Nov. 1981 82X75198 US GOV AGENCIES

940. KOERNER, H.: **Technical evaluation report on the Fluid Dynamic Panel Symposium on Subsonic/Transonic Configuration/Aerodynamics.**: AGARD-AR-146 ISBN-92-835-1380-0 AD-A096824 Jan. 1981 81N23431

Papers presented at the various sessions are highlighted. Topics cover prediction methods, weapons carriage, configuration optimization, powered jet interaction, and multicomponent interference. Conclusions from the discussion are considered from the point of view of computational fluid dynamics, interference aspects, and optimization. Recommendations are offered.

941. MORGRET, C. H.; DIX, R. E.; LIJEWSKI, L. E.: **Development of analytical and experimental techniques for determining store airload distributions.** (American Institute of Aeronautics and Astronautics, Atmospheric Flight Mechanics Conference, Albuquerque, NM, Aug. 19-21, 1981, AIAA 81-1896.) Journal of Spacecraft and Rockets, vol. 19, Nov.-Dec. 1982, p. 489-495. 83A13077

(Previously cited in issue 21, p. 3613, Accession no. 81A44584)

This report contains information on aerodynamic loads, computerized simulation, external stores, free flow, load distribution (forces), scale models, wind tunnel tests, aerodynamic interference, aircraft performance, angle of attack, flow velocity, Mach Number, and structural design.

942. MORGRET, C. H.; DIX, R. E.; LIJEWSKI, L. E.: **Development of analytical and experimental techniques for the determination of distributed loads on stores.**: AIAA PAPER 81-1896 American Institute of Aeronautics and Astronautics, Atmospheric Flight Mechanics Conference, Albuquerque, NM, Aug. 19-21, 1981, 10 p. 81A44584

A semiempirical computer code has been developed for the prediction of the distribution of static aerodynamic loads acting on a store both in the free stream and in the interference flow field of an aircraft. The code is applicable to a wide range of configurations for subsonic through supersonic Mach numbers and angles of attack to approximately 45 deg. Wind tunnel tests were conducted using a 1/4-scale pressure model, a 1/4-scale force model divided into four segments and a three-segment 1/20-scale force model of the same configuration. Integrated pressure data, segmented force data, and previously obtained single balance data agreed well, and computer code predictions correlated well with the experimental data.

943. HAINES, A. B.: **Prospects for exploiting favorable and minimizing adverse aerodynamic interference in external store installations.**: Sept. 1980 81N15996

External store installations are frequently a source of considerable adverse aerodynamic interference giving large increases in drag, reductions in usable lift, and poor store release characteristics. Research has shown how this adverse interference can be greatly alleviated or even transformed into favorable interference. Some of the available evidence for a wide variety of arrangements are reviewed. The nature of the interference, both adverse and favorable, is described, particular emphasis being placed on the major adverse interference in standard multiple carriers and in some underwing installations. The possible benefits of wing tip carriage and carefully arranged underfuselage arrays are noted. The fact that dramatic improvements might be possible by adopting a radical approach to store carriage is stressed.

944. PUGH, P. G. : **Weapon-aircraft interaction.** In VKI Missile Aerodyn., Suppl., 22 p (See 83N75602 15-15) 1979 83N75605

This report contains information on aerodynamic interference, aircraft performance, external stores, aerodynamic drag, body-wing configurations, lift and swept wings.

945. PUGH, P. G.: **Weapon-aircraft interaction.**: RAE-TM-AERO-1731 BR61786 Oct. 1977 80N72050

This report contains information on aerodynamic interference, aircraft stability, aircraft control, carriages, and wing-fuselage stores.

946. HARDY, B. C. : **A computer program to estimate the interference on a wing due to an engine nacelle at subsonic speeds. Part 1: Description of the method.**: RAE-TR-75074-PT-1 BR48380 July 1975 75X77433 US GOV AGENCIES

This report contains information on aerodynamic interference, nacelles, wing loading, prediction analysis techniques.

947. MAIDEN, D. L.: **Effect of inlet cowl external profile and external stores on the drag of a fighter airplane model with two-dimensional ramp inlets (U).**: NASA-TM-X-2682 L-8501 Feb. 1975 75X10179 US GOV AGENCIES AND CONTRACTORS

The investigation was conducted in the Langley 4-foot supersonic pressure tunnel at a Mach number of 2.01 at angles of attack from about -3 deg to 6 deg and in the Langley 16-foot transonic tunnel at Mach numbers of 0.6, 0.85, and 0.9 at angles of attack generally from -4 deg to 10 deg. Two inlet cowl external profile configurations were studied; one blunt and the other sharp. The effect of the variation of the external profile of the inlet cowl on supersonic and subsonic performance is discussed. In addition to the inlet study, the effect of the installation of externally mounted air-to-air missiles was investigated at Mach 2.01.

948. TURNER, C. L.: **Aerodynamic interference between a wing and store.**: AD-748348 GA/MC/72-6 June 1972 73N13005

Simplified wing and store models are used to determine the aerodynamic interference effects between an aircraft and a store carried beneath its wing. Inviscid flow characteristics are calculated and the results compared to an experimental wind tunnel study. The resulting vertical forces are comparable to those from the wind tunnel study when modeling the wing with a single horseshoe vortex. The remaining forces and moments are not predicted accurately. Methods for correcting the differences are suggested. Modeling the wing with multiple horseshoe vortices changes the side force values to values comparable to those from the wind tunnel study. This indicates that the method can be extended to correct the other forces and moments to more realistic values.

9.2 LANDING GEAR EFFECTS

949. MCCOMB, HARVEY G., JR.; TANNER, JOHN A.: **Topics in landing gear dynamics research at NASA Langley.**: (ICAS, Congress, 15th, London, England, Sept. 7-12, 1986, Proceedings. Volume 2, p. 1390-1397) Journal of Aircraft (ISSN 0021-8669), vol. 25, Jan. 1988, p. 84-93. Previously cited in issue 24, p. 3542, Accession no. 86A49120. 88A30387

This report contains information on aircraft design, dynamic characteristics, landing gear, NASA programs, research and development, active control, aircraft tires, attitude control runway conditions, and spray ingestion.

950. DAUGHERTY, ROBERT H.; STUBBS, SANDY M.: **Flow rate and trajectory of water spray produced by an aircraft tire.**: SAE PAPER 861626 SAE, Aerospace Technology Conference and Exposition, Long Beach, CA, Oct. 13-16, 1986. 9 p. 87A32582

One of the risks associated with wet runway aircraft operation is the ingestion of water spray produced by an aircraft's tires into its engines.This problem can be especially dangerous at or near rotation speed on the takeoff roll. An experimental investigation was conducted in the NASA Langley Research Center Hydrodynamics Research Facility to measure the flow rate and trajectory of water spray produced by an aircraft nose tire operating on a flooded runway. The effects of various parameters on the spray patterns including distance aft of nosewheel, speed, load, and water depth were evaluated. Variations in the spray pattern caused by the airflow about primary structure such as the fuselage and wing are discussed. A discussion of events in and near the tire footprint concerning spray generation is included.

951. MCCOMB, H. G., JR.; TANNER, J. A.: **Topics in landing gear dynamics research at NASA Langley.**: ICAS, Congress, 15th, London,England, September 7-12, 1986, Proceedings. Volume 2 (86A48976 24-01). New York, American Institute of Aeronautics and Astronautics, Inc., 1986, p. 1390-1397. 86A49120

Four topics in landing gear dynamics are discussed. Three of these topics are subjects of recent research: tilt steering phenomenon, water spray ingestion on flooded runways, and actively controlled landing gear. The fourth topic is a description of a major facility recently enhanced in capability.

952. YAGER, T. J.; STUBBS, S. M.; MCCARTY, J. L.: **The effect of chine tires on nose gear water-spray characteristics of a twin engine airplane.**: NASA-TM-X-72695 May 1975 75N23555

An experimental investigation was performed to evaluate the effectiveness of nose gear chine tires in eliminating or minimizing the engine spray ingestion problem encountered on several occasions by the Merlin 4, a twin-engine propjet airplane. A study of the photographic and television coverage indicated that under similar test conditions the spray from the chine tires presented less of a potential engine spray ingestion problem than the conventional tires. Neither tire configuration appeared to pose any ingestion problem at aircraft speeds in excess of the hydroplaning speed for each tire, however, significant differences were noted in the spray patterns of the two

sets of tires at sub-hydroplaning speeds. At sub-hydroplaning speeds, the conventional tires produced substantial spray above the wing which approached the general area of the engine air inlet at lower test speeds. The chine tires produced two distinct spray plumes at sub-hydroplaning speeds: one low-level plume which presented no apparent threat of ingestion, and one which at most test speeds was observed to be below the wing leading edge and thus displaced from the intakes on the engine nacelle.

9.3 AERODYNAMIC INTERFERENCE

953. COTTRELL, CHARLES J.; MARTINEZ, AGUSTO; CHAPMAN, GARY T.: **Study of multibody aerodynamic interference at transonic Mach numbers**. (AIAA, Aerospace Sciences Meeting, 25th, Reno, NV, Jan. 12-15, 1987, AIAA Paper 87-0519) AIAA Journal (ISSN 0001-1452), vol. 26, May 1988, p. 553-560. Previously cited in issue 08, p. 1042, Accession no. 87A22682. 1988. 88A50332

This report contains information on aerodynamic interference, external stores, transonic flow, flow visualization, mach number, and wind tunnel tests.

954. Engine Response to Distorted Inflow Conditions.: AGARD-CP-400 ISBN-92-835-0412-7 AD-A182635 1987. 87N24464

955. COTTRELL, CHARLES J.; MARTINEZ, AGUSTO; CHAPMAN, GARY T.: **A study of multi-body aerodynamic interference at transonic Mach numbers.**: AIAA PAPER 87-0519 AIAA, Aerospace Sciences Meeting, 25th, Reno, NV, Jan. 12-15, 1987. 10 p. Jan. 1987 87A22682

A wind tunnel experiment involving single, double, and triple combinations of mutually interfering generic, unfinned aircraft stores has been conducted. Each combination of stores was tested at Mach numbers from 0.60 to 1.20 and at angles of attack from 0 to 25 deg for the single store and from 0 to 6 deg for the double and triple store configurations. Extensive axial and circumferential pressure and flow visualization data at each store location were obtained. Euler solutions for each configuration at 0 deg incidence have been generated and compared with experimental data. This comparison indicates an Euler flow solver can yield accurate predictions of the location and magnitude of multibody interference provided an appropriate grid is used and the viscous effects associated with these configurations remain small. The data indicate multibody interference in the transonic region increases as the freestream Mach number approaches 1 from either direction, and subsides as the Mach number moves away from sonic conditions. This interference is characterized by a large, localized reduction in pressure on the inboard surfaces of the bodies which results in forces that draw the configuration closer together.

956. VOLKOV, V. F.; DEMYANENKO, V. S.; DERUNOV, Y. K.; BRODETSKIY, M. D.; RAFAELYANTS, A. A.: **Aerodynamic interference in flow past three dimensional bodies (selected articles).**: AD-B102475L FTD-ID(RS)T-1261-85 June 10, 1986 87X70009 US GOV AGENCIES

957. NIELSEN, J. N. : **Arrays of bodies of revolution for minimum wave drag**. (AIAA, Aerospace Sciences Meeting, 23rd, Reno, NV, Jan. 14-17,1985, AIAA Paper 85-0449) Journal of Aircraft (ISSN 0021-8669), vol. 22, Oct. 1985, p. 901-909. Previously cited in issue 07, p. 854, Accession no.85A19758. Oct. 1985 85A49136

This report contains information on bodies of revolution, drag reduction, minimum drag, wave drag, aerodynamic interference, drag measurement, external stores, supersonic and transonic flows.

958. NIELSEN, J. N. : **Arrays for minimum wave drag of bodies of revolution.**: AIAA PAPER 85-0449 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 23rd, Reno, NV, Jan. 14-17, 1985. 13 p. Jan. 1985 85A19758

The wave drag of two identical Sears-Haack bodies at transonic and supersonic speeds has been determined by using the supersonic area rule. The solution is found for these bodies displaced parallel to each other, both laterally and longitudinally. The results show that the drag of a pair of bodies can be either doubled, or nearly halved, depending upon the lateral and longitudinal spacings of the bodies. The magnitude of this drag is determined by the degree of mutual interference between the bodies. It is shown how reductions in wave drag can be obtained by proper spacing of external bodies. The regions of favorable mutual interference are delineated. It is also shown how to apply the two-body results to many-body arrays. Some remarks are made on applying the results to store-airframe interference and on further aspects of the store-airframe drag problem.

959. CHRISTOPHER, P. A. T.; SHAW, C. T.: **The use of multipoles for calculating the aerodynamic interference between bodies of revolution**. Journal of Aircraft (ISSN 0021-8669), vol. 21, Sept. 1984, p.673-679. 84A44509

A method is presented which uses the higher-order solutions of Laplace's equation to generate the flows between bodies of revolution which have complicated mutual aerodynamic interference. Such a situation commonly exists when several aircraft stores are grouped together under an aircraft. The method is shown to be a consistent approximation to the surface source methods, and gives good results for bodies with smooth meridian profiles. In particular, the improvement in accuracy due to the higher-order singularities is very evident, showing a possible modification to current techniques which lack this refinement. The method provides the basis of a simple calculation procedure which can be used, within the limits of linear theory for axisymmetric bodies, for flow speeds up to the critical speed. In particular, unless nonlinearities caused, for example, by transonic flows are evident, then the method could be used instead of the expensive computational fluid dynamics programs currently being developed.

960. ERDOS, J. I.; MANDEL, M.; RAY, R. G.: **Aeromechanical applications of favorable supersonic interference. Volume 4: Performance of a Mach 4.5 aircraft concept employing various body-wing and nacelle-wing interference design options (U)**: AD-C032943L GASL-TR-267 AFWAL-TR-82-3020-VOL-4 July 1983 84X72795 US GOV AGENCIES

961. ERDOS, J. I.; RAY, R.; MANDEL, M.: **Aeromechanical applications of favorable supersonic interference. Volume 3: Performance of a Mach 3 aircraft concept based on nacelle-wing interference (U)**: AD-C032942L GASL-TR-266 AFWAL-TR-82-3020-VOL-3 AUG. 1983 84X72794 US GOV AGENCIES

962. GOLUBKINA, O. A.: **Interference of lifting surfaces in plane-parallel supersonic gas flows.**: TsAGI, Uchenye Zapiski, vol. 10, no.1, 1979, p. 19-25. In Russian. 80A27128

In the present paper, the interference problem is solved for lifting surfaces situated in a plane-parallel supersonic flow. The lifting surfaces are arranged in tandem, such that the oncoming flow becomes nonuniform. The additional potential is determined within the framework of small perturbation theory from a partial differential equation derived from the present analysis. A solution of this equation is obtained by the method of successive approximations. The lifting force is shown to increase with increasing distance between the airfoils, the interference playing a major part in the increase.

963. KULFAN, R. M.: **Application of hypersonic favorable aerodynamic interference concepts to supersonic aircraft.**: AIAA PAPER 78-1458 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Conference, Los Angeles, Calif., Aug. 21-23, 1978, 28 p. 78A52042

A study was made to identify hypersonic favorable aerodynamic interference concepts for application to supersonic aircraft. Preliminary aerodynamic analysis defined key design parameters, and scoped potential aerodynamic efficiency improvements. The study included supersonic biplanes, ring wings, parasol wings, wave rider concepts, and flat-top wing/body arrangements. Results indicate the parasol wing concept offers the greatest potential aerodynamic benefits for the study conditions. However, the best aerodynamic concept is very dependent on the design Mach number, and on the airplane component size relationships. It is shown that existing aerodynamic design/analysis methods can be used for parasol wing aerodynamics studies.

964. Subsonic/Transonic Configuration Aerodynamics.: AGARD-CP-285 ISBN-92-835-0276-0 AD-A094086 Sept. 1980 81N15991

This report contains information on aerodynamic configurations, aerodynamic interference, body-wing configurations, external stores, flow distribution, prediction analysis techniques, subsonic and transonic flows.

965. TRIEBSTEIN, H.: **Investigation of unsteady interference effects on oscillating lifting surface and bodies in incompressible flow**. In its Contrib. to Steady and Unsteady Aerodyn., p 269-280 (See 78N17004 08-02) 10 Aug. 1977 78N17023

Unsteady differential pressure distribution investigations on wing-horizontal tail surfaces, wing-body, wing-external store combinations, and plane cascades are reported. The effect of separate parameters, such as reduced frequency and model geometry, on the unsteady interference effects of the separate lifting surfaces and bodies was studied in particular. Experimental results of unsteady pressure distributions were compared with theoretical values and

selected results are presented. Measurements were carried out in the 3-m low velocity wind tunnel and in the test stand for plane cascade of the DFVLR-AVA.

966. CHAUDHURI, S. N.: **Studies in transonic aerodynamic interference.**: AD-A064016 AFATL-TR-77-113 Sept. 1977 79N77432

This report contains information on aerodynamic interference, body wing configurations, external stores, transonic flow, flow characteristics, flow distribution, and perturbations.

967. KULFAN, R. M.; YOSHIHARA, H.; LORD, B. J.; FRIEBEL, G. O.: **Application of supersonic favorable aerodynamic interference to fighter type aircraft.** AD-B029985L AFFDL-TR-78-33 D180-24059-1978. 85X73061 US GOV AGENCIES

968. PURSHOUSE, M.; NANGIA, R. K.: **Applications of linearised supersonic wing theory to the calculation of some aircraft interference flows.**: Computational methods and problems in aeronautical fluid dynamics. (77A12551 02-02) London and New York, Academic Press, 1976, p. 383-423. Research supported by the British Aircraft Corp. 77A12566

The Mach box method is used to provide a numerical formulation of linearized supersonic wing theory for calculating some typical aircraft interference flows. In this method, the disturbance regions in a wing plane are overlaid by a grid of rectangular constant source strength Mach boxes, which become square when a coordinate transformation to the equivalent problem at Mach 1.414 is introduced. Flow perturbations produced at a point in the downstream zone from a source are calculated by appropriate aerodynamic influence coefficient relations. In the calculation of an underwing flowfield at a typical intake location, the effect of leading edge droop on the intake flowfield is studied. Other applications are the calculation of the interference field at a fin location arising from asymmetric elevon deflection, and the mutual interference field produced by two 65-deg-sweep delta wings.

969. MARTIN, F. W.; SAUNDERS, G., JR.; CUTCHINS, M. A.: **Mutual aerodynamic interference effects for multiple bodies of revolution and distorted bodies of revolution.**: AD-B013340L AFATL-TR-76-47 April 1976 77X70516 US GOV AGENCIES

This report contains information on aerodynamic interference, bodies of revolution, boundary layer separation, wing-fuselage stores, flow distribution, pressure distribution, and separated flow.

970. MARTIN, F. W.; SMITH, C. J.; SAUNDERS, G. H., JR.: **Mutual aerodynamic interference effects for two axisymmetric bodies.**: AD-915784L AFATL-TR-73-161 Aug. 1973 74X72277 US GOV AGENCIES

This report contains information on aerodynamic interference, external stores, flow distribution, aerodynamic forces, perturbation theory.

971. ZECH, A.: **Aerodynamic analysis, part 2, vol. 5-6 (U).**: FT-200-N-0002 Nov. 1967 82X72354 US GOV AGENCIES

This report covers the following topics: aerodynamic configurations; aerodynamic drag; aerodynamic interference; friction drag; jet aircraft; fighter aircraft; V/STOL aircraft; boattails; external stores; flow characteristics; inlet flow; and supersonic drag.

9.4 FLOW DISTURBANCES/DISTORTION

972. SHI, WANGXING: **The characteristics of the turbulence generator and the simulation of the flow regulation.**: Journal of Propulsion Technology (ISSN 1001-4055), April 1989, p. 26-30, 72. In Chinese, with abstract in English. 89A41119

The unsteadiness of pitot pressure distortion flow formed by an axial symmetric turbulence generator is investigated. The flow can be classified as steady or unsteady depending on whether the location and the dimension of the low-pressure zone in the flow change with time. The measurement repeatability of the distortion factor in steady flow is better than that in unsteady flow. A simple and available method to simulate flow profiles is also described.

973. SHI, WANGXING: **Regulation of distortion flowfield by axisymmetric turbulence generators.**: Journal of Aerospace Power (ISSN 1000-8055), vol. 3, July 1988, p. 262-264, 286. In Chinese, with abstract in English. July 1977 89A11062

This paper provides a regulation law for the distortion flowfield of axisymmetric turbulence generators, which can meet the demands for simulating the static and dynamic inlet distortions simultaneously. The distortion flowfield is regulated by variation of the throat area ratio and the working-pressure ratio. The experiments show that the absolute deviation of the turbulence regulated by this law is less than 0.01.

974. TIERNEY, SHERYL S.: **F-16/LANTIRN (Low Altitude Navigation and Targeting Infrared for Night) flying qualities evaluation.**: AD-B109795L AFFTC-TR-86-40 Jan. 1987 87X72635 US GOV AGENCIES

This report contains information on aerodynamic characteristics and stability, air navigation, flight characteristics, engine inlets, external stores, jet aircraft, and jet engines.

975. WILLIAMS, D. D.: **Review of current knowledge on engine response to distorted inflow conditions**. In AGARD Engine Response to Distorted Inflow Conditions, 32 p (See 87N24464 18-07) March 1987 87N24465

An overview to the 68th Propulsion and Energetics Panel (PEP) Specialists Meeting is presented. Some current aspects of time-variant, spatial total-pressure distortion and other forms such as swirl, static-pressure distortion, planar-wave perturbations of total pressure, and total temperature distortion are reviewed. Engine response considerations include the influence of engine spool coupling on stability, developments in the modeling of total-pressure circumferential extent effects, and swirl/total-pressure interactions. Guidelines for the formulation of distortion descriptors and performance/stability assessments are reviewed.

976. AULEHLA, F.; SCHMITZ, D. M.: **New trends in intake/engine compatibility assessment**. In AGARD Engine Response to Distorted Inflow Conditions, 24 p (See 87N24464 18-07) March 1987 87N24467

The measurement of dynamic distortion requires considerable effort in instrumentation and data processing. Distortion measurement methods which are time and cost efficient are described. Experience gained from the Tornado aircraft indicates that the relevance of dynamic distortion on intake/engine compatibility has been overestimated and, in fact, swirl emerged as the decisive compatibility parameter. Also, during the Airbus A-300 APU intake development swirl turned out to be an important criterion. In conclusion, it is argued whether in many cases dynamic distortion measurements can be avoided in favor of swirl measurements in combination with simplified methods for dynamic distortion predictions based on steady state measurements and, in some cases, on statistical models.

977. POVINELLI, LOUIS A.; TOWNE, CHARLES E.: **Viscous analyses for flow through subsonic and supersonic intakes**. In AGARD Engine Response to Distorted Inflow Conditions, 20 p (See 87N24464 18-07) March 1987 87N24469

A parabolized Navier-Stokes code was used to analyze a number of diffusers typical of a modern inlet design. The effect of curvature of the diffuser centerline and transitioning cross sections was evaluated to determine the primary cause of the flow distortion in the duct. Results are presented for S-shaped intakes with circular and transitioning cross sections. Special emphasis is placed on verification of the analysis to accurately predict distorted flow fields resulting from pressure-driven secondary flows. The effect of vortex generators on reducing the distortion of intakes is presented. Comparisons of the experimental and analytical total pressure contours at the exit of the intake exhibit good agreement. In the case of supersonic inlets, computations of the inlet flow field reveal that large secondary flow regions may be generated just inside of the intake. These strong flows may lead to separated flow regions and cause pronounced distortions upstream of the compressor.

978. BIESIADNY, THOMAS J.; BRAITHWAITE, WILLIS M.; SOEDER, RONALDH.; ABDELWAHAB, MAHMOOD: **Summary of investigations of engine response to distorted inlet conditions**. In AGARD Engine Response to Distorted Inflow Conditions, 21 p (See 87N24464 18-07) March 1987 87N24477

A survey is presented of experimental and analytical experience of the NASA Lewis Research Center in engine response to inlet temperature and pressure distortions. Results of experimental investigations and analytical modeling are reviewed together with a description of the hardware and the techniques employed. Distortion devices successfully simulated inlet distortion, and knowledge was gained on compression system response to different types of distortion. A list of NASA research references is included.

979. EYRAUD, J. L.; AUZOLLE, F.: **Unsteady pressure data acquisition and processing in air inlet distortion surveys.**: (National Seminar on Flight Research, Test and Development, Bangalore, India, Sept. 2, 3, 1987) Aeronautical Society of India, Journal (ISSN 0001-9267), vol. 39, May-Aug. 1987, p. 107-112. 88A30208

The survey of compatibility between the aircraft air intake and the engine is an essential step in the development of a new product. This work is based on, in addition to other means, experimental activities requiring the use of quite comprehensive data-acquisition and processing equipment to provide the best analysis conditions. The equipment described in this paper illustrates the range of systems now operational at SNECMA. The emphasis is placed on the importance of real-time test monitoring which conditions to a large extent the architecture of the original equipment which had to be developed, and its consistency from the stage of model tests to flight tests.

980. BION, J. R.: **Characteristics of air intake flow fields and evaluation of the loss of compression surge margin due to flowfield distortions in the compressor inlet plane.**: ONERA, TP NO. 1986-98 (ICAS, Congress, 15th, London, England, Sept. 7-12, 1986) ONERA, TP, no. 1986-98, 1986, 10 p. 87A21024

This report contains information on flow distortion, inlet flow, internal compression inlets, surges, ducted flow, engine tests, flow visualization, pressure measurement, and wind tunnel tests.

981. BIESIADNY, T. J.; BRAITHWAITE, W. M.; SOEDER, R. H.; ABDELWAHAB, M.: **Summary of investigations of engine response to distorted inlet conditions.**: NASA-TM-87317 E-3048 NAS 1.15:87317 1986 86N26336

A survey is presented of experimental and analytical experience of the NASA Lewis Research Center in engine response to inlet temperature and pressure distortions. This includes a description of the hardware and techniques employed, and a summary of the highlights of experimental investigations and analytical modeling. Distortion devices successfully simulated inlet distortion, and knowledge was gained about compression system response to different types of distortion. A list of NASA research references is included.

982. SCHWEIKHARD, W. G.; CHEN, Y. S.: **Statistical prediction of dynamic distortion of inlet flow using minimum dynamic measurement. An application to the Melick statistical method and inlet flow dynamic distortion prediction without RMS measurements.**: NASA-CR-176764 NAS 1.26:176764 April 1986 86N24933

The Melick method of inlet flow dynamic distortion prediction by statistical means is outlined. A hypothetic vortex model is used as the basis for the mathematical formulations. The main variables are identified by matching the theoretical total pressure rms ratio with the measured total pressure rms ratio. Data comparisons, using the HiMAT inlet test data set, indicate satisfactory prediction of the dynamic peak distortion for cases with boundary layer control device vortex generators. A method for the dynamic probe selection was developed. Validity of the probe selection criteria is demonstrated by comparing the reduced-probe predictions with the 40-probe predictions. It is indicated that the number of dynamic probes can be reduced to as few as two and still retain good accuracy.

983. GRASHOF, J.: **Numerical investigation of three-dimensional transonic flow through air intakes disturbed by a missile plume.**: AIAA PAPER 83-1854 American Institute of Aeronautics and Astronautics, Applied Aerodynamics Conference, Danvers, MA, July 13-15, 1983. 9 p. Sponsorship: Bundesministerium der Verteidigung. 83A38682

Some disturbances originating from the plume of a launched missile may be captured by the inlet and related distortions may jeopardize engine operations. In order to avoid dangerous situations and to achieve an efficient weapon/aircraft integration detailed knowledge of the plume influences are needed which presumably cannot be gained by experiments. A prediction method based on the Euler equations is proposed to analyze the flow problem. The physical assumptions and the features of the computational method are outlined. A realistic test case is studied and the results are compared with those without a missile plume. Remarkable flow distortions induced by the rocket plume are observed on the outer surface of the air intake and in the inlet channel.

984. KACHHARA, N. L.; SAXENA, G. B.: **Study of critical geometry two-dimensional diffusers having distorted inlet flow.**: Institution of Engineers (India), Journal, Mechanical Engineering Division, vol. 62, Mar. 1982, p. 149-153. 82A41269

A study of the performance of near critical geometry two-dimensional diffusers having distorted inlet flow shows that when specifying the critical geometry of a diffuser it is also necessary to mention the type of inlet flow. A relationship has been obtained for the outlet peak velocity which has been verified experimentally. The shape factor at the outlet of these near critical geometry diffusers is found to be related to the local blockage factor.

985. DE SIERVI, F.; VIGUIER, H. C.; GREITZER, E. M.; TAN, C. S.: **Mechanisms of inlet-vortex formation.**: AD-A135471 AFOSR-TR-83-1004Journal of Fluid Mechanics, vol. 124, Nov. 1982, p. 173-207. 83A16260

The results of theoretical and experimental investigation of the causative agents for formation of a vortex flow in gas turbine inlets are presented.The theoretical examination was carried out with a secondary flow approach in order to calculate the three-dimensional vorticity field characteristic of the phenomenon. Experiments were run in a water tunnel using hydrogen-bubble flow visualization. Trials were run with a boundary layer velocity profile, a jet profile, and with clockwise and counterclockwise shear for an inlet with 90 deg of yaw, and with an inlet in an irrotational flow. One mechanism discovered had a vertical velocity component in the ambient vorticity. It was amplified during intake when the vortex lines were drawn into the inlet. A second, entirely separate, mechanism was determined to be present in a cross wind intake in irrotational flow. It occurred when the circulation varied along the length of the inlet, producing a trailing vortex system.

986. MACE, J.; SEDLOCK, D.: **A perspective on developing new inlet distortion measurement and predictive methods.**: AIAA PAPER 81-1589 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 10 p. 81A40964

Various statistical properties of compressor face total fluctuations, such as coherence and correlation coefficients, are estimated from wind tunnel data taken from an 0.15 scale F-16 inlet. It is shown that: (1) estimation of the correlation coefficient between engine face dynamic probes shows statistically significant correlations between adjacent probes on the same rake; (2) the pressure correlation is independent of location within either a low or high total pressure region and could be expressed as a scalar function of distance within those two regions; and (3) a systematic procedure based on multiple regression is found to estimate peak distortion using substantially fewer than the usual 40 dynamic probes at a compressor face.

987. SANDERS, M. E.: **An evaluation of statistical methods for the prediction of maximum time-variant inlet total pressure distortion.**: AIAA PAPER 80-1110 AIAA, SAE, and ASME, Joint Propulsion Conference, 16th, Hartford, Conn., June 30-July 2, 1980, AIAA 11 p. 80A38918

The paper presents an evaluation of statistical methods for the prediction of maximum time-variant inlet total pressure distortion. Of the three methods investigated, the Motycka method shows the most promise; the predicted distortion values and patterns agree with those measured. However, the method must be modified to account for the nature of the inlet total pressure fluctuations. The Jacocks method predicts distortion values with reasonable accuracy, but the ADC requirement makes the method unsuitable for the most inlet programs. The Melick method is recommended for use during early subscale model inlet tests for the determination of maximum time-variant distortion values; also this method can be used as a nonline analysis tool for configuration selection and test direction at any stage of aircraft development.

988. TINDELL, R.: **High-flow inlets**. In NASA Lewis Research Center Inlet Workshop, p 355-382. 1977 86N72221

This report contains information on air ducts, boundary layer control, engine inlets, flow distortion, supersonic cruise aircraft research, supersonic flow, aerodynamic drag, design analysis, inlet pressure, life cycle costs, and wind tunnel tests.

989. WELGE, H. R.; JONES, J. R.: **Douglas' subsonic inlet design approach**. In NASA Lewis Research Center Inlet Workshop, p 7-24 (See 86N72197 18-01) 1977 86N72198

This report contains information on aerodynamic drag, boundary layers, separation, cowlings, engine inlets, flow distortion, flight tests, and wind tunnel tests.

990. FABRE, D.; FONTANEL, J.; GOUSSE, M.: **Full scale test of the C22 target in the ONERA S1MA wind tunnel**: ONERA, TP NO. 1982-95 (NATO, AGARD, Symposium sur l'Aerodynamique des Missiles, Trondheim, Norway, Sept. 20-22, 1982.) ONERA, TP no. 1982-95, 1982. 16 p. In French. 83A18430

Wind tunnel tests with the turbojet equipped C22 target drone are described, including corrections made for the wind tunnel environment and comparisons with data from flight tests. The C22 is radio remote controlled, has a maximum altitude of 12,000 m, a top speed of M 0.7-0.9, and is recoverable after flight. The S1MA wind tunnel was employed with a full scale model to test the drag effects of the positioning of the turbojet and the antennas, fittings, etc. The data were corrected for the influence of the walls, the mount for the model, and the engine presence. Strain-gage balances were employed to quantify the drag caused by the vehicle appurtenances. No interface was detected between the jet nozzle and the target airframe. Some influence on the drag was caused by the exhaust, while overall the wind tunnel tests provided drag measurements which were confirmed in flight tests.

10.0 NOISE

10.1 GENERAL SURVEYS

991. High Speed Civil Transport Study: Special factors. NASA-CR-181881 NAS 1.26:181881 1990. 90N28537

Studies relating to environmental factors associated with high speed civil transports were conducted. Projected total engine emissions for year 2015 fleets of several subsonic/supersonic transport fleet scenarios, discussion of sonic boom reduction methods, discussion of community noise level requirements, fuels considerations, and air traffic control impact are presented.

992. KREJSA, EUGENE A.; COOPER, BETH A.; HALL, DAVID G.; KHAVARAN, ABBAS: **Noise measurements from an ejector suppressor nozzle in the NASA Lewis 9- by 15-foot low speed wind tunnel.** NASA-TM-103628 E-5717 NAS 1.15:103628 AIAA-90-3983 1990. 91N11493

Acoustic results are presented of a cooperative nozzle test program between NASA and Pratt and Whitney, conducted in the NASA-Lewis 9 x 15 ft Anechoic Wind Tunnel. The nozzle tested was the P and W Hypermix Nozzle concept, a 2-D lobed mixer nozzle followed by a short ejector section made to promote rapid mixing of the induced ejector nozzle flow. Acoustic and aerodynamic measurements were made to determine the amount of ejector pumping, degree of mixing, and noise reduction achieved. A series of tests were run to verify the acoustic quality of this tunnel. The results indicated that the tunnel test section is reasonably anechoic but that background noise can limit the amount of suppression observed from suppressor nozzles. Also, a possible internal noise was observed in the air supply system. The P and W ejector suppressor nozzle demonstrated the potential of this concept to significantly reduce jet noise. Significant reduction in low frequency noise was achieved by increasing the peak jet noise frequency. This was accomplished by breaking the jet into segments with smaller dimensions than those of the baseline nozzle. Variations in ejector parameters had little effect on the noise for the geometries and the range of temperatures and pressure ratios tested.

993. SEINER, JOHN M.; KREJSA, EUGENE A.: **Supersonic jet noise and the high speed civil transport.** AIAA PAPER 89-2358 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 25th, Monterey, CA, July 10-13, 1989. 24 p. 1989. 89A46772

An evaluation is made of the comparative advantages of prospective SST engine noise-suppression systems, with a view to their effectiveness in meeting the federally-mandated community noise standards of FAR 36 Stage III. A noise-suppression system must be capable of removing at least 4 EPNdB of noise percent thrust loss at takeoff. While none of the suppressors presently discussed is capable of meeting this goal, the inverted velocity profile/annular convergent-divergent plug/acoustically-treated ejector suppressor combination of configurational elements appears to represent the most efficient noise-control apparatus. Noncircular cross-section nozzle geometries also furnish a general noise reduction advantage over circular ones.

994. Airport noise technology challenge for a high speed civil transport. NASA-CR-185213 NAS 1.26:185213 PWA-FR-20559 1990 90X10304 <u>DOMESTIC</u>

Comparisons of sideline jet noise levels were made for five engine concepts that incorporate components, materials and structures that will be available in 1995 to 2000. Eight jet noise reduction concepts were screened and their benefits estimated. Three propulsion concepts: a Variable Stream Control Engine (VSCE), a Turbine Bypass Engine (TBE) and an Inverted Exhaust Turbofan (IETF), and four noise reduction concepts: inverted velocity profile (IVP), treated ejector nozzle (TEN), mechanical noise suppressor (MNS) and thermal acoustic shield (TAS) were evaluated in an advanced 750,000

pound, 300 passenger Mach 3.2 civil transport. The VSCE with the four noise reduction concepts could only achieve a range of 2800 n.mi, while the TBE and IETF also could only achieve ranges of 2430 and 2370 n.mi, respectively, when the engines were sized to meet the FAR Part 36 Stage 3 sideline jet noise of 102.6 EPNdB.

995. STERN, A. M.; PERACCHIO, A. A.: **The challenge of reducing supersonic civil transport propulsion noise**. AIAA PAPER 89-2363 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 25th, Monterey, CA, July 10-13, 1989. 6 p. 89A46776

Achievement of FAR 36 Stage 3 noise levels presents a challenge. Techniques such as, for example, the use of inverted velocity profile jet exhausts, suppressor/ejectors, thermo-acoustic shields, are shown to provide significant suppression, but not enough to meet Stage 3. Additional suppression is required and achievement is suggested through the use of devices that increase exhaust flow, aircraft operational techniques and engine/airframe integration. Needed additional experimental programs on noise suppression and analytical studies are identified.

996. SEINER, JOHN M.; KREJSA, EUGENE A.: **Supersonic jet noise and the high speed civil transport**. AIAA PAPER 89-2358 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 25th, Monterey, CA, July 10-13, 1989. 24 p. 89A46772

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997. SMITH, MICHAEL J. T.: **Aircraft noise**. Cambridge and New York, Cambridge University Press, 1989, 370 p. 90A24253

A comprehensive account is given of the factors affecting the generation of aircraft noise by subsonic and supersonic commercial aircraft airframes and the range of pure-jet, bypass fan, and propeller propulsion systems. A development history and current status evaluation is presented for methods of noise suppression in low and high-bypass airliner powerplants, especially during low-altitude takeoff and landing operations in the vicinity of airports. The cases of Concorde SST operations near airports, and the characteristics of supersonic-cruise 'sonic booms',

998. SMITH, M. J. T.; LOWRIE, B. W.; BROOKS, J. R.; BUSHELL, K. W.: **Future supersonic transport noise - Lessons from the past**.: AIAA PAPER 88-2989 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 16 p. 1988. 88A53121

While the small, carefully operated Concorde SST fleet has come to be accepted at important airports, next-generation SSTs will be larger than Concorde and must therefore enlist advanced techniques to comply with FAR Part 36, Stage 3. This entails the use of an engine cycle which, during takeoff, is equivalent to a high bypass ratio turbofan with a mean exhaust velocity no greater than 400 m/sec. Such variable-cycle engines, whether for Mach 2 or 3 cruise, are technically possible but difficult to develop. Variable engine cycle is further entailed by overland flight requirements, which require subsonic flight to prevent sonic boom overpressures.

999. NIHART, GENE L.; BROWN, JEFFREY J.: **Supersonic propulsion systems and community noise suppression concepts**. AIAA PAPER 88-2986 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 9 p. 88A46491

After a brief evaluation of advanced SST propulsion cycles, the ability of various alternative designs to meet community noise suppression requirements during prospective international airport operations are discussed. Attention is given to the noise suppression features that may allow SST variable thermodynamic cycle engines incorporating numerous variable-geometry

1000. SMITH, M. J. T.; LOWRIE, B. W.; BROOKS, J. R.; BUSHELL, K. W.: **Future supersonic transport noise - Lessons from the past**. AIAA PAPER 88-2989 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 16 p. 88A53121

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1001. Supersonic transport noise reduction technology program, phase 2. R75AEG135-3 QR-11 1984. 85N70908

1002. SEINER, J. M.: **Advances in high speed jet aeroacoustics.** AIAA PAPER 84-2275. American Institute of Aeronautics and Astronautics and NASA, Aeroacoustics Conference, 9th, Williamsburg, VA, Oct. 15-17, 1984. 41 p. 1984. 85A13959

This paper provides an assessment from an experimental point of view of the present understanding of high speed jet noise primarily as it pertains to shock containing supersonic jet plumes. The nature of this assessment involves an examination of the complex flow and related acoustic field associated with this problem. A certain emphasis is placed on prediction of the near acoustic field to satisfy a motivation driven by a new set of guiding principles, namely the high performance tactical fighter and second generation space transportation vehicles. The review concludes that after weighing all the experimental evidence, only after consideration of the role of large scale coherent structure is adopted can a consistent unifying theme be achieved to physically interpret and properly predict noise generation by the fundamental mechanisms.

1003. RIEL, F. J.; ROSE, P. M.: **Adhesive bonded noise suppression structures for commercial and military aircraft.** SAMPE Quarterly (ISSN 0036-0821), vol. 16, Oct. 1984, p. 45-50. 85A14172

Noise suppression requirements for future commercial and military aircraft are reviewed, and methods for reducing noise emissions are summarized. The use of adhesive bonded sandwich structures for acoustic treatment in nacelles is defined, and process parameters and special processes and quality control techniques are discussed. The relative advantage of various concepts are outlined from the standpoint of cost, acoustic performance, and structural efficiency.

1004. SMITH, M. J. T.: **Commercial aircraft noise.** PNR-90206 1984. 85N12665

The state of the art in aircraft noise reduction is reviewed. Turbomachinery and exhaust noise; the use of advanced signal detection and source location techniques; and installation effects are discussed. Noise levels are close to those in the pre-jet era. A technology plateau has been reached, where no single engine noise source can be regarded as dominant, and further progress is possible only if significant improvement is made on all fronts.

1005. ZORUMSKI, W. E.: **Aircraft noise prediction program theoretical manual, part 2.** NASA-TM-83199-PT-2 L-14805-PT-2 1982. 82N19947

Detailed prediction methods for specific aircraft noise sources are given. These sources are airframe noise, combustion noise, fan noise, single and dual stream jet noise, and turbine noise. Modifications to the NASA methods which comply with the International Civil Aviation Organization standard method for aircraft noise prediction are given.

1006. ZORUMSKI, W. E.: **Aircraft noise prediction program theoretical manual, part 1.** NASA-TM-83199-PT-1 L-14805-PT-1 1982. 82N19946

Aircraft noise prediction theoretical methods are given. The prediction of data which affect noise generation and propagation is addressed. These data include the aircraft flight dynamics, the source noise parameters, and the propagation effects.

1007. CLARK, B. J.: **Computer program to predict aircraft noise level.s** NASA-TP-1913 E-733 1981. 81N33947

Methods developed at the NASA Lewis Research Center for predicting the noise contributions from various aircraft noise sources were programmed to predict aircraft noise levels either in flight or in ground tests. The noise sources include fan inlet and exhaust, jet, flap (for powered lift), core (combustor), turbine, and airframe. Noise propagation corrections are available for atmospheric attenuation, ground reflections, extra ground attenuation, and shielding. Outputs can include spectra, overall sound pressure level, perceived noise level, tone-weighted perceived noise level, and effective perceived noise level at locations specified by the user. Footprint contour coordinates and approximate footprint areas can also be calculated. Inputs and outputs can be in either System

International or U.S. customary units. The subroutines for each noise source and propagation correction are described. A complete listing is given.

1008. TESTER, B. J.; FISHER, M. J.: **Engine noise source breakdown - Theory, simulation and results.** AIAA PAPER 81-2040 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 7th, Palo Alto, CA, Oct. 5-7, 1981, 11 p. 1981. 81A48620

Cross-spectrum measurements in the far-field of an aero-engine are processed to form a source image along the engine axis. The intensity of the intake, bypass, core and mixing noise sources is estimated from the image, provided the sources are well separated on the wavelength scale. The 'best squares' fit procedure is used to automate the source breakdown calculation by eliminating the source-image stage of data analysis, thereby permitting larger volumes of data to be processed. Numerical studies and practical results demonstrate that the method can be used at far lower frequencies than those for which individual source contributions could be discerned from a resolution limited source image. Far less comprehensive microphone arrays are required, since there is no general aliasing problem. Application of this technique to the separate core and jet mixing noise on a Viper engine yields a range of valuable data, previously unavailable; the technique is not restricted to a line array of point sources, but can be extended to an arbitrary array of either compact or noncompact sources.

1009. HUNT, R. B.: **Noise and economic study for supersonic cruise airplane research.** NASA-CR-165423 PWA-5701-22 1981. 81X10332 **US GOV AGENCIES AND CONTRACTORS**

Analytical comparisons of engine/airplane direct operating cost versus traded noise were generated for three study engines based on the National Aeronautics and Space Administration Advanced Supersonic Transport (AST)-105-1 airplane concept adjusted to a design range of 7408 km (4000 naut mi). The three study engines evaluated were the low bypass engine, variable stream control engine, and inverted flow engine. The economic comparisons were evaluated on a 5926 km (3200 naut mi) mission with a 556 km (300 naut mi) subsonic leg, which was chosen as being representative of North Atlantic service.

1010. MUNIN, A. G.; CHEREMUKHIN, G. A.; SHIPOV, R. A.: **Noise characteristics of supersonic passenger planes.** In: Aeroacoustics. (80A34386 13-71) Moscow, Izdatel'stvo Nauka, 1980, p. 3-12. In Russian. 80A34387

In the present paper, the noise characteristics of a supersonic transport are studied as a function of the craft's performance and specifications. The results of a parametric analysis of the influence of noise abatement measures on the parameters of the airplane are examined, showing that the noise-optimal cruising parameters differ appreciably from the fuel-optimal parameters. The noise-generating features of an SST and methods of reducing noise are discussed. It is shown that substantial noise abatement can be achieved by increasing the L/D ratio and by using variable-cycle engines.

1011. OKEEFE, J. V.; MANGIAROTTY, R. A.; PICKUP, N.: **Current problems and the future in advanced supersonic transport noise.** AIAA PAPER 80-1056 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 6th, Hartford, Conn., June 4-6, 1980, 9 p. 80A35997

Noise control technology developed during the past decade may enable the United States to resume development of an advanced supersonic transport (SST) that will give improved levels of noise. Such developments include coannular and nonconcentric nozzles, thermal acoustic shields, and mechanical suppressors to control jet noise, the primary source of SST noise. Advanced operational procedures during takeoff and landing will reduce SST community noise. However, because the success of noise suppression devices cannot be predicted with certainty, more noise-control technology must be developed and flight tested to ensure that SST jet and

1012. PADULA, S. L.: **Prediction of noise constrained optimum takeoff procedures.**: AIAA PAPER 80-1055 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 6th, Hartford, Conn., June 4-6, 1980, 12 p. 80A35996

An optimization method is used to predict safe, maximum-performance takeoff procedures which satisfy noise constraints at multiple observer locations. The takeoff flight is represented by two-degree-of-freedom dynamical equations with aircraft angle-of-attack and engine power setting as control functions. The engine thrust, mass flow and noise source parameters are assumed to be given functions of the engine power setting and aircraft Mach number. Effective Perceived Noise Levels at the observers are treated as functionals of the control functions. The method is demonstrated by

applying it to an Advanced Supersonic Transport aircraft design. The results indicate that automated takeoff procedures (continuously varying controls) can be used to significantly reduce community and certification noise without jeopardizing safety or degrading performance.

1013. HAYS, A. P.: **Optimization of takeoff flight paths with respect to FAR Part 36 noise using dynamic programming**. In: Inter-noise 80: Noise control for the 80's; Proceedings of the Ninth International Conference on Noise Control Engineering, Miami, FL, December 8-10, 1980. Volume 2. (81A46351 22-71) Poughkeepsie, NY, Noise Control Foundation, 1980, p. 851-854. 81A46371

A method of scheduling the thrust and speed of a second generation supersonic transport (SST) to minimize takeoff noise on the ground is presented. Dynamic programming is selected as the optimization method, which is used for trajectory optimization and noise minimization. The number of decision-making stages is set to three, and sideline noise remains reasonably constant due to reduced ground attenuation on the sideline noise. The value of minimum traded noise is found from three computer runs, and the optimal control is selected based on minimum cumulative noise energy at the flyover noise microphone. The program can quickly evaluate changes of the aerodynamic propulsion or acoustic characteristics of an SST, and can be modified to determine optimal trajectories for different noise receiver distributions.

1014. DRIVER, C.; MAGLIERI, D. J.: **Some unique characteristics of supersonic cruise vehicles and their effect on airport community noise**. AIAA PAPER 80-0859 American Institute of Aeronautics and Astronautics, International Meeting and Technical Display on Global Technology 2000, Baltimore, Md., May 6-8, 1980, 10 p. 80A32861

The paper examines the differences between the supersonic and subsonic commercial aircraft in terms of their configuration, aerodynamic characteristics, propulsion systems, and the manner of operation. The unique characteristics of supersonic cruise vehicles should provide improved airport-community noise exposures if the vehicle is permitted to operate at its most efficient and effective flight modes. It is concluded that noise exposure levels for supersonic cruise vehicles can be comparable to those of its equivalent subsonic counterpart of that time period.

1015. ELDRED, K. M.: **Noise control technology evaluation for supersonic transport category aircraft**. PB82-169616 BBN-4052 EPA-550/9-81-323 1980. 82N75187

1016. GRANTHAM, W. D.; SMITH, P. M.: **Development of SCR Aircraft takeoff and landing procedures for community noise abatement and their impact on flight safety**. In its Supersonic Cruise Res. 1979, Pt. 1, p 299-333 (See 81N17981 09-01) 1980. 81N17994

Piloted simulator studies to determine takeoff and landing procedures for a supersonic cruise transport concept that result in predicted community noise levels which meet current Federal Aviation Administration (FAA) standards are discussed. The results indicate that with the use of advanced procedures, the subject simulated aircraft meets the FAA traded noise levels during takeoff and landing utilizing average flight crew skills. The advanced takeoff procedures developed involved violating three of the current Federal Aviation Regulations (FAR) noise test conditions. These were: (1) thrust cutbacks at altitudes below 214 meters (700 ft); (2) thrust cutback level below those presently allowed; and (3) configuration change, other than raising the landing gear. It was not necessary to violate any FAR noise test conditions during landing approach. It was determined that the advanced procedures developed do not compromise flight safety. Automation of some of the aircraft functions reduced pilot workload, and the development of a simple head-up display to assist in the takeoff flight mode proved to be adequate.

1017. STONE, J. R.; GUTIERREZ, O. A.: **Status of noise technology for advanced supersonic cruise aircraft**. In NASA Langley Research Center Supersonic Cruise Res. 1979, Pt. 1, p 493-518 (See 81N17981 09-01) 1980. 81N18002

Developments in acoustic technology applicable to advanced supersonic cruise aircraft, particularly those which relate to jet noise and its suppression are reviewed. The noise reducing potential of high radius ratio, inverted velocity profile coannular jets is demonstrated by model scale results from a wide range of nozzle geometries, including some simulated flight cases. These results were verified statistically at large scale on a variable cycle engine (VCE) testbed. A preliminary assessment of potential VCE noise sources such as fan and core noise is made, based on the testbed data. Recent advances in the understanding of flight effects are reviewed. The status of component noise prediction methods is assessed on the

basis of recent test data, and the remaining problem areas are outlined.

1018. KAPPER, C. Y.: **Validation of aircraft noise prediction program.** NASA-CR-159047 1979. 79N25843

Predictions made with NASA's aircraft noise prediction program (ANOPP) were compared with flyover noise data. A data base of six flyover noise runs for the DC-10-40/JT9D-59A configuration was used. For all power settings, ANOPP consistently underpredicted the low frequency spectral levels, overpredicted high frequency spectral levels and, consequently, overpredicted the inlet and aft PNLT time histories.

1019. BREMOND, J.: **The evaluation of annoyance provoked by aircraft noise by means of opinion surveys.** Medecine Aeronautique et Spatiale, Medecine Subaquatique et Hyperbare, vol. 18, 4th Quarter, 1979, p. 269-274. In French. 80A32597

1020. BARTEL, C.; SUTHERLAND, L. C.: **Noise exposure of civil air carrier airplanes through the year 2000. Volume 1: Methods, procedures, results.** EPA-550/9-79-313-1 WR-78-11-VOL-1 1979. 81N12644

A noise prediction model was used to show the possible effectiveness of reducing aircraft noise exposure by modifications to FAR 36 which would progressively lower noise limits for newly designed aircraft, and by using alternative power cutback procedures coupled with minor variations on approach procedures. Exposure was measured in terms of land area and number of people subjected to various levels of noise from L(dn) 60 to 80 db. Subsonic aircraft were emphasized; however, the isolated exposure of only supersonic operations was also analyzed. Results show that the application to subsonic aircraft of the noise technology certification rules for 1980 and 1985 proposed by EPA will show a substantial decrease in noise exposure in future years but the result will not be felt until well beyond the year 2000. A more immediate achievement noise reduction is possible by using an improved takeoff procedure. The proposed ALPA/NWA MaxCutback procedure offers additional noise reduction on an average for the nation's airports over that provided by the AC91-30 procedure for current technology aircraft.

1021. BARTEL, C.; SUTHERLAND, L. C.: **Noise exposure of civil aircarrier airplanes through the year 2000. Volume 2: Appendices A through F** EPA-550/9-70-313-2 WR-78-11-VOL-2 1979. 81N12645

Airports with more than 10 jet departures per year are listed and procedures are given for forecasting the moderate and expansive growth of civil air carriers to the year 2000. Graphs show the noise characteristics and assumed performance characteristics for each aircraft classification studied. The expected range in noise exposure to the year 2000 due to supersonic aircraft operations is analyzed for various scenarios. The impact of both the average airport and at the nations level for all aircraft classifications examined is forecasted.

1022. SHEPHERD, K. P.: **The effect of the duration of jet aircraft flyover sounds on judged annoyance.** NASA-CR-159132 1979. 80N10859

The effect of the duration of jet aircraft flyover sounds on humans and the annoyance factor are examined. A nine point numerical category scaling technique is utilized for the study. Changes in the spectral characteristics of aircraft sounds caused by atmospheric attenuation are discussed. The effect of Doppler shifts using aircraft noises with minimal pure tone content is reported. The spectral content of sounds independent of duration and Doppler shift are examined by analysis of variance.

1023. BLANKENSHIP, G. L.; LOW, J. K. C.; WATKINS, J. A.; MERRIMAN, J. E.: **Effect of forward motion on engine noise.** NASA-CR-134954 MDC-J7708 1977. 78N10093

Methods used to determine a procedure for correcting static engine data for the effects of forward motion are described. Data were analyzed from airplane flyover and static-engine tests with a JT8D-109 low-bypass-ratio turbofan engine installed on a DC-9-30, with a CF6-6D high-bypass-ratio turbofan engine installed on a DC-10-10, and with a JT9D-59A high-bypass-ratio turbofan engine installed on a DC-10-40. The observed differences between the static and the flyover data bases are discussed in terms of noise generation, convective amplification, atmospheric propagation, and engine installation. The results indicate that each noise source must be adjusted separately for forward-motion and installation effects and then projected to flight conditions as a function of source-path angle, directivity angle, and acoustic range relative to the microphones on the ground.

1024. MERRIMAN, J. E.; GOOD, R. C.; LOW, J. K. C.; YEE, P. M.; BLANKENSHIP, G. L.: **Forward motion and installation effects on engine noise.** AIAA PAPER 76-584 American Institute of Aeronautics and Astronautics, Aero-Acoustics Conference, 3rd, Palo Alto, Calif., July 20-23, 1976, 11 p. 1976. 76A41397

In order to investigate the effects of forward motion and nacelle installation on airplane flyover noise, static engine and airplane flyover noise data for a refanned JT8D-109 low-bypass-ratio turbofan engine installed on a DC-9-30 airplane and a CF6-6D high-bypass-ratio turbofan engine installed on a DC-10-10 airplane were analyzed. Differences between static-projected and flyover noise data are discussed in terms of noise source generation, convective amplification, propagation, and the engine installation. The results presented indicate that each engine noise source should be adjusted separately for forward motion and installation effects and projected to flight conditions as a function of the source path angle, directivity angle, and acoustic range relative to the microphones on the ground.

10.2 SONIC BOOM

1025. AURIOL, A.; LECOMTE, C.; THERY, C.: **The sonic boom problem** IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 149-154. 1990. 91A10964

An overview of the sonic boom problem is presented including a description of the physical phenomenon, results on sonic boom effects, and considerations for the aircraft designer. Detailed graphs, descriptions and results of various sonic boom tests are provided. It is shown that the weight and the volume of the aircraft play an important role in the intensity of the boom. The part due to the volume is of particular importance as it deteriorates rapidly with altitude. It is also shown that Mach number (except close to Mach 1) has little influence on the intensity of the boom beneath the flight path. However, it has a considerable effect on the width of the boom path. The most important problem to overcome is the startle effect on humans and intensive research in this area will be required. It is concluded that a diminution of the sonic boom path could be achieved and this would lead to a decrease of supersonic flight restricted areas.

1026. High Speed Civil Transport Study: Special factors. NASA-CR-181881 NAS 1.26:181881 1990. 90N28537

Studies relating to environmental factors associated with high speed civil transports were conducted. Projected total engine emissions for year 2015 fleets of several subsonic/supersonic transport fleet scenarios, discussion of sonic boom reduction methods, discussion of community noise level requirements, fuels considerations, and air traffic control impact are presented.

1027. CHEUNG, SAMSON H.; EDWARDS, THOMAS A.; LAWRENCE, SCOTT : **Application of CFD to sonic boom near and mid flow-field prediction.**: AIAA PAPER 90-3999 AIAA, Aeroacoustics Conference, 13th, Tallahassee, FL, Oct. 22-24, 1990. 10 p. 1990. 91A12512

A three-dimensional parabolized Navier-Stokes (PNS) code has been used to calculate the supersonic overpressures from three different geometries at near- and mid-flow fields. Wind-tunnel data is used for code validation. Comparison of the computed results with different grid refinements is shown in this paper. It is observed that a large number of grid points is needed to resolve the tail shock/expansion fan interaction. Therefore, an adaptive grid approach is employed to calculate the flow field. The agreement between the numerical results and the wind-tunnel data confirms that computational fluid dynamics can be applied to the problem of sonic boom prediction.

1028. SICLARI, M. J.; DARDEN, C. M.: **An Euler code prediction of near field to midfield sonic boom pressure signatures.**: AIAA PAPER 90-4000 AIAA, Aeroacoustics Conference, 13th, Tallahassee, FL, Oct. 22-24, 1990. 15 p. 1990. 91A12513

A new approach is presented for computing sonic boom pressure signatures in the near field to midfield that utilizes a fully three-dimensional Euler finite volume code capable of analyzing complex geometries. Both linear and nonlinear sonic boom methodologies exist but for the most part rely primarily on equivalent area distributions for the prediction of far field pressure signatures.This is due to the absence of a flexible nonlinear methodology that can predict near field pressure signatures generated by three-dimensional aircraft geometries. It is the intention of the present study to present a nonlinear Euler method than can fill this gap and supply the needed near field signature data for many of the existing sonic boom codes.

1029. MACK, ROBERT J.; NEEDLEMAN, KATHY E.: **The design of two sonic boom wind tunnel models from conceptual aircraft which cruise at Mach numbers of 2.0 and 3.0.** AIAA PAPER 90-4026 AIAA, Aeroacoustics Conference, 13th, Tallahassee, FL, Oct. 22-24, 1990. 8 p 1990. 91A12536

A method for designing wind tunnel models of conceptual, low-boom, supersonic cruise aircraft is presented. Also included is a review of the procedures used to design the conceptual low-boom aircraft. In the discussion, problems unique to, and encountered during, the design of both the conceptual aircraft and the wind tunnel models are outlined. The sensitivity of low-boom characteristics in the aircraft design to control the volume and lift equivalent area distributions was emphasized. Solutions to these problems are reported; especially the two which led to the design of the wind tunnel model support stings.

1030. NEEDLEMAN, KATHY E.; MACK, ROBERT J.: **A study of sonic boom overpressure trends with respect to weight, altitude, Mach number, and vehicle shaping.** AIAA PAPER 90-0367 AIAA, Aerospace Sciences Meeting, 28th, Reno, NV, Jan. 8-11, 1990. 9 p. 1990. 90A19816

This paper presents and discusses trends in nose shock overpressure generated by two conceptual Mach 2.0 configurations. One configuration was designed for high aerodynamic efficiency, while the other was designed to produce a low boom, shaped-overpressure signature. Aerodynamic lift, sonic boom minimization, and Mach-sliced/area-rule codes were used to analyze and compute the sonic boom characteristics of both configurations with respect to cruise Mach number, weight, and altitude. The influence of these parameters on the overpressure and the overpressure trends are discussed and conclusions are given.

1031. MACK, ROBERT J.; NEEDLEMAN, KATHY E.: **A methodology for designing aircraft to low sonic boom constraints.** NASA-TM-4246 L-16768 NAS 1.15:4246 1990. 90X36163 NASA PERS. ONLY

A method for designing conceptual supersonic cruise aircraft to meet low sonic boom requirements is outlined and described. The aircraft design is guided through a systematic evolution from initial three view to a final numerical model description, while the designer using the method controls the integration of low sonic boom, high supersonic aerodynamic efficiency, adequate low speed handling, and reasonable structure and materials technologies. Some experience in preliminary aircraft design and in the use of various analytical and numerical codes is required for integrating the volume and lift requirements throughout the design process.

1032. MACK, ROBERT J.; NEEDLEMAN, KATHY E.: **A semi-empirical method for obtaining fuselage normal areas from fuselage Mach-sliced areas.**: NASA-TM-4228 L-16614 NAS 1.15:4228 1990. 90X36121 NASA PERS. ONLY

An aircraft designed to meet low sonic boom or shaped ground overpressure signature requirements has a volume and lift equivalent area distribution which is in close agreement with the equivalent areas of a desired theoretical curve. Final-stage design modifications of the aircraft's geometry to meet this requirement are usually made through adjustments to the fuselage normal cross-section areas that are derived from the corresponding fuselage equivalent areas by iterative methods. The time required to obtain a good agreement between the desired low-boom area distribution and the conceptual aircraft total area distribution can be reduced by using a semi-empirical method which eliminates much of the final trial-and-error iteration previously employed. Fuselages from conceptual aircraft designed to generate low sonic boom ground overpressures at cruise Mach numbers of 2.0 and 3.0 were used as examples to examine the method's capabilities and limitations. Results indicated that the method has merit as a design tool consistent with other linear theory methods.

1033. DARDEN, CHRISTINE M.; POWELL, CLEMANS A.; HAYES, WALLACE D.; GEORGE, ALBERT R.; PIERCE, ALLAN D.: **Status of sonic boom methodology and understanding.** NASA-CP-3027 L-16567 NAS 1.55:3027 1989. 89N23415

In January 1988, approximately 60 representatives of industry, academia, government, and the military gathered at NASA-Langley for a 2 day workshop on the state-of-the-art of sonic boom physics, methodology, and understanding. The purpose of the workshop was to assess the sonic boom area, to determine areas where additional sonic boom research is needed, and to establish some strategies and priorities in this sonic boom research. Attendees included many internationally recognized sonic boom experts who had been very active in the Supersonic Transport (SST) and Supersonic Cruise Aircraft Research Programs of the 60's and 70's. Summaries of the assessed state-of-the-art and the research needs in theory, minimization, atmospheric effects during propagation, and human response are given.

1034. Aircraft sonic boom: Studies on aircraft flight, aircraft design, and measurement. Citations from the NTIS data base PB81-805665 NTIS/PS-79/0264 1981. 81N77103

1035. DARDEN, C. M.: **Charts for determining potential minimum sonic-boom overpressures for supersonic cruise aircraft.** NASA-TP-1820 L-14190 1981. 81N21016

Charts which give an estimation of minimum achievable sonic-boom levels for supersonic cruise aircraft are presented. A minimization method based on modified linear theory was analyzed. Results show several combinations of Mach number, altitude, and aircraft length and weight. Overpressure and impulse values are given for two types of sonic boom signatures for each of these conditions: (1) a flat top or minimum overpressure signature which has a pressure plateau behind the initial shock, and (2) a minimum shock signature which allows a pressure rise aft er the initial shock. R results are given for the effects of nose shape.

1036. MACK, R. J.; DARDEN, C. M.: **Wind-tunnel investigation of the validity of a sonic-boom-minimization concept.** NASA-TP-1421 L-12661 1979. 80N10102

The Langley unitary plan unitary plan wind tunnel was used to determine the validity of a sonic-boom-minimization theory. Five models - two reference and three low-boom constrained - were tested at design Mach numbers of 1.5 and 2.7. Results show that the pressure signatures generated by the low-boom models had significantly lower overpressure levels than those produced by the reference models and that small changes in the Mach number and/or the lift caused relatively small changes in the signature shape and overpressure level. Boundary-layer effects were found in the signature shape and overpressure level. Boundary-layer effects were found to be sizable on the low-boom models, and when viscous corrections were included in the analysis, improved agreement between the predicted and the measured signatures was noted. Since this agreement was better, it was concluded that the minimization method was definitely valid at Mach 1.5 and was probably valid at Mach 2.7, with further work needed to resolve the uncertainty.

1037. MACK, R. J.; DARDEN, C. M.: **Some effects of applying sonic boom minimization to supersonic cruise aircraft design.** AIAA PAPER 79-0652 American Institute of Aeronautics and Astronautics, Aeroacoustics Conference, 5th, Seattle, Wash., Mar. 12-14, 1979, 8 p 1979. 79A26927

This paper presents a discussion of an aircraft shaping method to control sonic boom over-pressure levels along with the analysis of wind-tunnel data which validated the method. The results indicate that the sonic boom minimization method can guide the design team choices of aircraft planform and component arrangement toward a low-boom-level configuration while permitting sufficient freedom and flexibility to satisfy other design criteria. Further, it is shown that off-design flight conditions do not drastically change the overpressure sonic boom shape and strength.

1038. MURRAY, R. H.: **Recent advances in Aeronautical and Space Medicine** AGARD-CP-265 ISBN-92-835-0250-7 AD-A078360 1979. 80N14678

1039. DARDEN, C. M.;MACK, R. J.: **Current research in sonic-boom minimization.** In its Proc. of the SCAR Conf., Pt.2, 17 p (See 77N18019 09-01) 1976. 77N18023

A review is given of several questions as yet unanswered in the area of sonic-boom research. Efforts, both here at Langley and elsewhere, in the area of minimization, human response, design techniques and in developing higher order propagation methods are discussed. In addition, a wind-tunnel test program being conducted to assess the validity of minimization methods based on a forward spike in the F-function is described.

11.0 AIRCRAFT AERODYNAMICS

11.1 LAMINAR FLOW TECHNOLOGIES

1040. PARIKH, P. G.; NAGEL, A. L.: **Application of laminar flow control to supersonic transport configurations.**: NASA-CR-181917 NAS 1.26:181917 1990. 90N25944

The feasibility and impact of implementing a laminar flow control system on a supersonic transport configuration were investigated. A hybrid laminar flow control scheme consisting of suction controlled and natural laminar flow was developed for a double-delta type wing planform. The required suction flow rates were determined from

boundary layer stability analyses using representative wing pressure distributions. A preliminary design of structural modifications needed to accommodate suction through a perforated titanium skin was carried out together with the ducting and systems needed to collect, compress and discharge the suction air. The benefits of reduced aerodynamic drag were weighed against the weight, volume and power requirement penalties of suction system installation in a mission performance and sizing program to assess the net benefits. The study showed a feasibility of achieving significant laminarization of the wing surface by use of a hybrid scheme, leading to an 8.2 percent reduction in the cruise drag. This resulted in an 8.5 percent reduction in the maximum takeoff weight and a 12 percent reduction in the fuel burn after the inclusion of the LFC system installation penalties. Several research needs were identified for a resolution of aerodynamics, structural and systems issues.

1041. RADESPIEL, R.; HORSTMANN, K. H.; REDEKER, G.: **Feasibility study on the design of a laminar flow nacelle.** AIAA PAPER 89-0640 AIAA, Aerospace Sciences Meeting, 27th, Reno, NV, Jan. 9-12, 1989. 12 p. 89A25506

This paper describes the design of a laminar flow nacelle. By means of natural laminar flow, e.g., nacelle contouring, laminar boundary layers on the nacelle surface can be maintained up to 60 percent of the nacelle length at cruise flight conditions. As well at take-off and landing conditions the inlet flow and the outside flow is free of flow separation. The overall drag coefficient of an aircraft equipped with two laminar flow nacelles is estimated to be reduced at cruise flight by Delta c(D) of about 0.0011.

1042. POWELL, A. G.; AGRAWAL, S.; LACEY, T. R.: **Feasibility and benefits of laminar flow control on supersonic cruise airplanes.** NASA-CR-181817 NAS 1.26:181817 1989. 89N26841

An evaluation was made of the applicability and benefits of laminar flow control (LFC) technology to supersonic cruise airplanes. Ancillary objectives were to identify the technical issues critical to supersonic LFC application, and to determine how those issues can be addressed through flight and wind-tunnel testing. Vehicle types studied include a Mach 2.2 supersonic transport configuration, a Mach 4.0 transport, and two Mach 2-class fighter concepts. Laminar flow control methodologies developed for subsonic and transonic wing laminarization were extended and applied. No intractable aerodynamic problems were found in applying LFC to airplanes of the Mach 2 class, even ones of large size. Improvements of 12 to 17 percent in lift-drag ratios were found. Several key technical issues, such as contamination avoidance and excrescence criteria were identified. Recommendations are made for their resolution. A need for an inverse supersonic wing design methodology is indicated.

1043. LAMB, MILTON; ABEYOUNIS, WILLIAM K.; PATTERSON, JAMES C., JR.; RE, RICHARD J.: **Natural laminar flow nacelle for transport aircraft.** In its Langley Symposium on Aerodynamics, Volume 1, p 445-460 (See 88N14926 07-01) 1986. 88N14949

The potential of laminar flow nacelles for reducing installed engine/nacelle drag was studied. The purpose was twofold: to experimentally verify a method for designing laminar flow nacelles and to determine the effect of installation on the extent of laminar flow on the nacelle and on the nacelle pressure distributions. The results of the isolated nacelle tests illustrated that laminar flow could be maintained over the desired length. Installing the nacelles on wing/pylon did not alter the extent of laminar flow occurring on the nacelles. The results illustrated that a significant drag reduction was achieved with this laminar flow design. Further drag reduction could be obtained with proper nacelle location and pylon contouring.

1044. SMITH, K. L.; KERR, W. B.; HARTMANN, G. L.; SKIRA, C. LAMB, M.; AABEYOUNIS, W. K.; PATTERSON, J. C., JR.: **Nacelle/pylon/wing integration on a transport model with a natural laminar flow nacelle.** NASA-TP-2439 L-15907 NAS 1.60:2439 1985. 85N29924

Tests were conducted in the Langley 16-Foot Transonic Tunnel at free-stream Mach numbers from 0.70 to 0.82 and angles of attack from -2.5 deg to 4.0 deg to determine if nacelle/pylon/wing integration affects the achievement of natural laminar flow on a long-duct flow-through nacelle for a high-wing transonic transport configuration. In order to fully assess the integration effect on a nacelle designed to achieve laminar flow, the effects of fixed and free nacelle transitions as well as nacelle longitudinal position and pylon contouring were obtained. The results indicate that the ability to achieve laminar flow on the nacelle is not significantly altered by nacelle/pylon/wing integration. The increment in installed drag between free and fixed transition for the nacelles on symmetrical pylons is essentially the calculated differences between turbulent and laminar flow on the nacelles. The installed drag of the contoured pylon is less than that of

the symmetrical pylon. The installed drag for the nacelles in a rearward position is greater than that for the nacelles in a forward position.

1045. YOUNGHANS, J. L.; LAHTI, D. J.: **Analytical and experimental studies on natural laminar flow nacelles.** AIAA PAPER 84-0034 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 22nd, Reno, NV, Jan. 9-12, 1984. 11 p. 84A17839

High speed proof of concept testing of a scale model natural laminar flow nacelle has been conducted with favorable results. Both isolated and installed tests have been conducted in the 16-Foot Wind Tunnel at NASA Langley to assess the feasibility of natural laminar flow to reduce nacelle external friction drag. Laminar flow drag reduction was verified in the isolated nacelle testing by force balance data as well as momentum rake integration. The installed nacelle drag reduction was measured by force balance only. Acenaphthene was utilized as a flow visualization tool to indicate the axial extent of laminar flow on the nacelle during both isolated and installed testing. The flow visualization data confirmed the presence of a significant region of laminar flow on the nacelle forebody as was also deduced by the measured drag reductions.

1046. Application of laminar flow control technology to optimum supersonic cruise. AD-803679 NOR-65-93 BMPR-9 1965. 80N71534

11.2 CONFIGURATIONS AND WING PLANFORMS

1047. VANDERVELDEN, ALEXANDER J. M.; KROO, ILAN: **The aerodynamic design of the oblique flying wing supersonic transport.**: NASA-CR-177552 A-90168 NAS 1.26:177552 1990. 90N28540

The aerodynamic design of a supersonic oblique flying wing is strongly influenced by the requirement that passengers must be accommodated inside the wing. It was revealed that thick oblique wings of very high sweep angle can be efficient at supersonic speeds when transonic normal Mach numbers are allowed on the upper surface of the wing. The goals were motivated by the ability to design a maximum thickness, minimum size oblique flying wing. A 2-D Navier-Stokes solver was used to design airfoils up to 16 percent thickness with specified lift, drag and pitching moment. A new method was developed to calculate the required pressure distribution on the wing based on the airfoil loading, normal Mach number distribution and theoretical knowledge of the minimum drag of oblique configurations at supersonic speeds. The wing mean surface for this pressure distribution was calculated using an inverse potential flow solver. The lift to drag ratio of this wing was significantly higher than that of a comparable delta wing for cruise speeds up to Mach 2.

1048. COVELL, PETER F.; HERNANDEZ, GLORIA; FLAMM, JEFFREY D.; ROSE, OLLIE: **Supersonic aerodynamic characteristics of a Mach 3 high-speed civil transport configuration.**: AIAA PAPER 90-3210 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Conference, Dayton, OH, Sept. 17-19, 1990. 10 p. 1990. 90A48836

The NASA-Langley AST31 high-speed civil transport (HSCT) configuration, a blended wing/fuselage concept scaled for 250-passenger carriage over 6500 nmi, has been subjected to both CFD and wind tunnel tests; the wind tunnel tests were conducted in the Mach 1.6-3.6 range. The inability of the linear theory method to accurately predict stability levels as well as nonlinear pitching moment characteristics demonstrates the need to undertake high-order analyses as early in the design process as possible. An HSCT laminar flow capability experimental study was conducted in order to simulate 50-percent laminar flow conditions, and thereby ascertain the difference in drag relative to fully turbulent conditions.

1049. MACK, ROBERT J.: **Aerodynamic characteristics of wings designed with a combined-theory method to cruise at a Mach number of 4.5.**: NASA-TP-2799 L-16333 NAS 1.60:2799 1988. 88N19420

A wind-tunnel study was conducted to determine the capability of a method combining linear theory and shock-expansion theory to design optimum camber surfaces for wings that will fly at high-supersonic/low-hypersonic speeds. Three force models (a flat-plate reference wing and two cambered and twisted wings) were used to obtain aerodynamic lift, drag, and pitching-moment data. A fourth pressure-orifice model was used to obtain surface-pressure data. All four wing models had the same planform, airfoil section, and centerbody area distribution. The design Mach number was 4.5, but data were also obtained at Mach numbers of 3.5 and 4.0. Results of these tests indicated that the use of airfoil

thickness as a theoretical optimum, camber-surface design constraint did not improve the aerodynamic efficiency or performance of a wing as compared with a wing that was designed with a zero-thickness airfoil (linear-theory) constraint.

1050. WERY, A. C.; KULFAN, R. M.; MANRO, M. E.: **Aeroelastic loads prediction for an arrow wing. Task 2: Evaluation of semi-empirical methods**. NASA-CR-3641 NAS 1.26:3641 1983. 83N22164

The development and evaluation of a semi empirical method to predict pressure distributions on a deformed wing by using an experimental data base in addition to a linear potential flow solution is described. The experimental data accounts for the effects of aeroelasticity by relating the pressures to a parameter which is influenced by the deflected shape. Several parameters were examined before the net leading edge suction coefficient was selected as the best.

1051. MACK, R. J.: **Wind-tunnel investigation of leading-edge thrust on arrow wings in supersonic flow**. NASA-TP-2167 L-15535 NAS 1.60:2167 1983. 83N31577

Six wing models were tested in the Langley Unitary Plan Wind Tunnel to identify and study leading-edge thrust at supersonic speeds. The tests were conducted at Mach numbers of 1.6, 1.8, 2.0, and 2.16, at a stagnation temperature of 125.0 F, and at Reynolds numbers per foot of 2.0 x 10 to the 6th power and 5.0 x 10 the 6th power. Test results showed that significant benefits from leading-edge thrust and nonlinear thickness effects can be obtained with very little airfoil bluntness, that these benefits were lost when the airfoil was severely blunted, and that such benefits seem to be found on wings with supersonic as well as subsonic leading edges.

1052. SCOTT, S. J.; NICKS, O. W.; IMBRIE, P. K.: **Effects of leading-edge devices on the low-speed aerodynamic characteristics of a highly-swept arrow-wing**. NASA-CR-172531 NAS 1.26:172531 1985. 85N22365

An investigation was conducted in the Texas A&M University 7 by 10 foot Low Speed Wind Tunnel to provide a direct comparison of the effect of several leading edge devices on the aerodynamic performance of a highly swept wing configuration. Analysis of the data indicates that for the configuration with undeflected leading edges, vortex separation first occurs on the outboard wing panel for angles of attack of approximately 2,and wing apex vortices become apparent for alpha or = 4 deg. However, the occurrence of the leading edge vortex flow may be postponed with leading edge devices. Of the devices considered, the most promising were a simple leading edge deflection of 30 deg and a leading edge slat system. The trailing edge flap effectiveness was found to be essentially the same for the configuration employing either of these more promising leading edge devices. Analysis of the lateral directional data showed that for all of the concepts considered, deflecting leading edge downward in an attempt to postpone leading edge vortex flows, has the favorable effect of reducing the effective dihedral.

1053. COE, P. L., JR.; KJELGAARD, S. O.; GENTRY, G. L., J: **Low-speed aerodynamic characteristics of a highly swept, untwisted uncambered arrow wing.**: NASA-TP-2176 NAS 1.60:2176 1983. 83N36000

An investigation was conducted in the Langley 4- by 7-Meter Tunnel to provide a detailed study of wing pressure distributions and forces and moments acting on a highly swept arrow-wing model at low Mach numbers (0.25). A limited investigation of the effect of spoilers at several locations was also conducted. Analysis of the pressure data shows that for the configuration with undeflected leading edges, vortex separation occurs on the outboard wing panel for angles of attack on the order of only 3 deg, whereas conventional leading-edge separation occurs at a nondimensional semispan station of 0.654 for the same incidence angle. The pressure data further show that vortex separation exists at wing stations more inboard for angles of attack on the order of 7 deg and that these vortices move inboard and forward with increasing angle of attack. The force and moment data show the expected nonlinear increments in lift and pitching moment and the increased drag associated with the vortex separation. The pressure data and corresponding force and moment data confirm that deflecting the entire wing leading edge uniformly to 30 deg is effective in forestalling the onset of flow separation to angles of attack greater than 8.6 deg; however, the inboard portion of the leading edge is overdeflected. The investigation further identifies the contribution of the trailing-edge flap deflection to the leading-edge upwash fields.

1054. CARLSON, H. W.; MILLER, D. S.: **Influence of leading-edge thrust on twisted and cambered wing design for supersonic cruise.** (American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Conference, Dayton, OH, Aug. 11-13, 1981,

AIAA Paper 81-1656) Journal of Aircraft (ISSN 0021-8669), vol. 20, May 1983, p. 440-445. 83A29018

1055. SCHOONOVER, W. E., JR.; OHLSON, W. E.: **Wind-tunnel investigation of vortex flaps on a highly swept interceptor configuration.**: International Council of the Aeronautical Sciences, Congress, 13th and AIAA Aircraft Systems and Technology Conference, Seattle, WA, August 22-27, 1982, Proceedings. Volume 2. (82A40876 20-01) New York, American Institute of Aeronautics and Astronautics, 1982, p. 1276-1290. 82A41004

A subsonic wind-tunnel investigation of the application of vortex flaps to a supersonic interceptor configuration is described. Experimental results are presented which indicate the aerodynamic effects of vortex-flap deflection, trailing-edge flap deflection, vortex flap chord and span, vertical stabilizers, and a highly cambered leading edge designed for attached flow. Data presented include longitudinal forces and moments, upper-surface pressure distributions, and oil- and smoke-flow visualization photographs. It is concluded that a full-span deployable vortex flap can provide a substantial performance improvement for this and other similar configurations.

1056. FRINK, N. T.: **Analytical study of vortex flaps on highly swept delta wings.**: International Council of the Aeronautical Sciences, Congress, 13th and AIAA Aircraft Systems and Technology Conference, Seattle, WA, August 22-27, 1982, Proceedings. Volume 2. (82A40876 20-01) New York, American Institute of Aeronautics and Astronautics, 1982, p. 1267-1275. 82A41003

This paper highlights some current results from ongoing analytical studies of vortex flaps on highly swept delta wings. A brief discussion of the vortex flow analysis tools is given along with comparisons of the theories to vortex flap force and pressure data. Theoretical trends in surface pressure distribution for both angle-of-attack variation and flap deflection are correctly predicted by Free Vortex Sheet theory. Also shown are some interesting calculations for attached-flow and vortex-flow flap hinge moments that indicate flaps utilizing vortex flow may generate less hinge moment than attached flow flaps. Finally, trailing-edge flap effects on leading-edge flap thrust potential are investigated and theory-experiment comparisons made.

1057. RAO, D. M.: **Upper Vortex Flap - A versatile surface for highly swept wings.**: International Council of the Aeronautical Sciences, Congress, 13th and AIAA Aircraft Systems and Technology Conference, Seattle, WA, August 22-27, 1982, Proceedings. Volume 2. (82A40876 20-01) New York, American Institute of Aeronautics and Astronautics, 1982, p. 1256-1266. NASA-supported research. 82A41002

The Upper Vortex Flap (UVF) is a multipurpose surface concept to improve the subsonic aerodynamics of highly swept delta wings. Hinged along the leading edges and deployed from the wing upper surface, the UVF generates a vortex inboard on the wing in addition to the leading-edge vortex acting on the flap. The relative suction levels on the wing and on the flap surface, governed by the flap angle and angle of attack, lead to a variety of functional applications viz. lift increment, drag modulation, lift/drag improvement and roll augmentation. This paper presents wind tunnel force and pressure measurements on a 74-deg flat plate delta to define the UVF-related vortex effects and to assess its potential as a versatile control surface in different angle-of-attack regimes.

1058. VOOGT, N.; SLOOFF, J. W.: **Advanced aerodynamic wing design for commercial transports - Review of a technology program in the Netherlands.**: International Council of the Aeronautical Sciences, Congress, 13th and AIAA Aircraft Systems and Technology Conference, Seattle, WA, August 22-27, 1982, Proceedings. Volume 2. (82A40876 20-01) New York, American Institute of Aeronautics and Astronautics, 1982, p. 1088-1098. 82A40985

An aerodynamic technology development program is described, whose main objectives are the formulation and validation of a computational procedure for the aerodynamic design of high aspect ratio wings for the transonic regime of short/medium range commercial aircraft, as well as the establishment of a transonic technology base. An inverse procedure has been formulated for the wing design task which allows the exercise of explicit control over wing geometry while approaching the target pressure distribution as closely as possible. Experience has been gained in relating target pressure distributions to off-design conditions through two-dimensional airfoil and three-dimensional wing studies, together with wind tunnel verifications that included the assessment of high Reynolds number characteristics. A wing-body configuration computational analysis capability for drag minimization studies has also been achieved by the program.

1059. REDDY, C. S.: **Effect of sweep angles on aerodynamic performance of double arrow wing - An analytical study**. Journal of Aircraft, vol. 18, Aug. 1981, p. 702, 703. 81A43397

Hybrid wing planforms are studied for adoption on supersonic transport and fighter aircraft. The free vortex sheet method is used to determine effects of the leading-edge sweep angles on the aerodynamic performance of a double arrow wing with a strake. Results show lift and drag increase with the increase of the inboard and outboard leading-edge sweep angles. However, the lift-to-drag ratio is little influenced by the changes in these sweep angles. Spanwise surface pressure distributions on the aft region are influenced by the inboard sweep angle while the outboard sweep angle has no effect on these pressures. Finally, the experimental data and predicted results are compared to show good agreement.

1060. CARLSON, H. W.; MILLER, D. S.: **The influence of leading-edge thrust on twisted and cambered wing design for supersonic cruise**. AIAA PAPER 81-1656 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Conference, Dayton, OH, Aug.11-13, 1981, 8 p. 81A43146

A study of leading-edge thrust phenomena at supersonic speeds has shown that although these forces are not large, they can be a significant factor in the design of wings for supersonic cruise. It is seen that the rather severe twisted and cambered wing surfaces resulting from the application of present design methods, which ignore leading-edge thrust, can be replaced by more moderate surfaces with little or no loss in aerodynamic efficiency if realistic possibilities for the attainment of some fraction of the theoretical thrust are taken into account.

1061. YIP, L. P.: **Low-speed wind-tunnel tests of a 1/10-scale model of an advanced arrow-wing supersonic cruise configuration designed for cruise at Mach 2.2.** NASA-TM-80152 1979. 80N10135

The low-speed longitudinal and lateral-directional characteristics of a scale model of an advanced arrow-wing supersonic cruise configuration were investigated in tests conducted at a Reynolds number of 4.19 x 10 to the 6th power based on the mean aerodynamic chord, with an angle of attack range from -6 deg to 23 deg and sideslip angle range from -15 deg to 20 deg. The effects of segmented leading-edge flaps, slotted trailing-edge flaps, horizontal and vertical tails, and ailerons and spoilers were determined. Extensive pressure data and flow visualization pictures with non-intrusive fluorescent mini-tufts were obtained.

1062. ROBINS, A. W.; CARLSON, H. W.; MACK, R. J.: **Supersonic wings with significant leading-edge thrust at cruise.** In its Supersonic Cruise Res. 1979, Pt. 1 p 229-246 (SEE 81N17981 09-01) 1980. 81N17990

Experimental/theoretical correlations are presented which show that significant levels of leading edge thrust are possible at supersonic speeds for certain planforms which match the theoretical thrust distribution potential with the supporting airfoil geometry. The analytical process employed spanwise distribution of both it and/or that component of full theoretical thrust which acts as vortex lift. Significantly improved aerodynamic performance in the moderate supersonic speed regime is indicated.

1063. BOBBITT, P. J.; MANRO, M. E.; KULFAN, R. M.: **The prediction of pressure distributions on an arrow-wing configuration including the effect of camber, twist, and a wing fin.** In its Supersonic Cruise Res. 1979, Pt. 1 p 59-115 (SEE 81N17981 09-01) 1980. 81N17984

Wind tunnel tests of an arrow wing body configuration consisting of flat, twisted, and cambered twisted wings were conducted at Mach numbers from 0.40 to 2.50 to provide an experimental data base for comparison with theoretical methods. A variety of leading and trailing edge control surface deflections were included in these tests, and in addition, the cambered twisted wing was tested with an outboard vertical fin to determine its effect on wing and control surface loads. Theory experiment comparisons show that current state of the art linear and nonlinear attached flow methods were adequate at small angles of attack typical of cruise conditions. The incremental effects of outboard fin, wing twist, and wing camber are most accurately predicted by the advanced panel method PANAIR. Results of the advanced panel separated flow method, obtained with an early version of the program, show promise that accurate detailed pressure predictions may soon be possible for an aeroelasticity deformed wing at high angles of attack.

1064. CARLSON, H. W.; MACK, R. J.: **Estimation of wing nonlinear aerodynamic characteristics at supersonic speeds**. NASA-TP-1718 L-13589 1980. 81N10004

A computational system for estimation of nonlinear aerodynamic characteristics of wings at supersonic speeds

was developed and was incorporated in a computer program. This corrected linearized theory method accounts for nonlinearities in the variation of basic pressure loadings with local surface slopes, predicts the degree of attainment of theoretical leading edge thrust, and provides an estimate of detached leading edge vortex loadings that result when the theoretical thrust forces are not fully realized.

1065. ROBINS, A. W.; CARLSON, H. W.; MACK, R. J.: **Supersonic wings with significant leading-edge thrust at cruise**. NASA-TP-1632 L-13316 1980. 80N21279

Experimental/theoretical correlations are presented which show that significant levels of leading-edge thrust are possible at supersonic speeds for certain planforms having the geometry to support the theoretical thrust-distribution potential. The new analytical process employed provides not only the level of leading-edge thrust attainable but also the spanwise distribution of both it and that component of full theoretical thrust which acts as vortex lift. Significantly improved aerodynamic performance in the moderate supersonic speed regime is indicated.

1066. CARLSON, H. W.; MACK, R. J.; BARGER, R. L.: **Estimation of attainable leading-edge thrust for wings at subsonic and supersonic speeds**. NASA-TP-1500 L-13032 1979. 80N10105

The factors which place limits on the theoretical leading edge thrust are identified. An empirical method for the estimation of attainable thrust is presented. The method is based on the use of simple sweep theory to permit a two dimensional analysis, the use of theoretical airfoil programs to define thrust dependence on local geometric characteristics, and the examination of experimental two dimensional airfoil data to define limitations imposed by local Mach numbers and Reynolds numbers. Comparisons of theoretical and experimental aerodynamic characteristics for a series of wing body configurations are examined.

1067. CARLSON, H. W.; MACK, R. J.: **Studies of leading-edge thrust phenomena**. AIAA PAPER 80-0325 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 11 p. 1980. 80A18315

A study of practical limitations on achievement of theoretical leading-edge thrust has been made and an empirical method for estimation of attainable thrust has been developed. The method is based on a theoretical analysis of a set of two-dimensional airfoils to define thrust dependence on airfoil geometric characteristics and arbitrarily defined limiting pressures, an examination of two-dimensional airfoil experimental data to provide an estimate of limiting pressure dependence on local Mach number and Reynolds number, and employment of simple sweep theory to adapt the method to three-dimensional wings. Because the method takes into account the spanwise variation of airfoil section characteristics, an opportunity is afforded for design by iteration to maximize the attainable thrust and the attendant performance benefits. The applicability of the method was demonstrated by comparisons of theoretical and experimental aerodynamic characteristics for a series of wing-body configurations. Generally, good predictions of the attainable thrust and its influence on lift and drag characteristics were obtained over a range of Mach numbers from 0.24 to 2.0.

1068. KULFAN, R. M.: **Wing geometry effects on leading-edge vortices**. AIAA PAPER 79-1872 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Meeting, New York, N.Y., Aug. 20-22, 1979, 38 p. 1979. 79A49341

Leading-edge vortices that form at off-design conditions can profoundly influence the aerodynamic characteristics of highly swept slender wings. A straightforward method that can predict wing geometry effects on the progressive spanwise development of leading-edge vortices is presented. This method, which can account for sweep, camber, twist, airfoil shape, flap deflections, and planform shape, is shown to be a useful tool for aerodynamic design studies. It is shown that suppressing the leading-edge vortex, particularly over the inboard portion of the wing, can cause considerable reduction in drag due to lift. Results of wing geometry parametric studies are shown.

1069. CARLSON, H. W.; MACK, R. J.: **Estimation of leading-edge thrust for supersonic wings of arbitrary planform**. NASA-TP-1270 L-12283 1978. 78N33051

A numerical method for the estimation of leading edge thrust for supersonic wings of arbitrary planform was developed and was programmed as an extension to an existing high speed digital computer method for prediction of wing pressure distributions. The accuracy of the method was assessed by comparison with linearized theory results for a series of flat delta wings. Application of the method to wings of arbitrary planform, both flat and cambered, is illustrated in several examples.

1070. MANRO, M. E.; MANNING, K. J. R.; HALLSTAFF, T. H.; ROGERS, J. T.: **Transonic pressure measurements and comparison of theory to experiment for an arrow-wing configuration.** Volume 1: Experimental data report, base configuration and effects of wing twist and leading-edge configuration NASA-CR-132727 D6-42670-2-VOL-1 1975. 76N11034

A wind tunnel test of an arrow-wing-body configuration consisting of flat and twisted wings, as well as a variety of leading- and trailing-edge control surface deflections, was conducted at Mach numbers from 0.4 to 1.1 to provide an experimental pressure data base for comparison with theoretical methods. Theory-to-experiment comparisons of detailed pressure distributions were made using current state-of-the-art attached and separated flow methods. The purpose of these comparisons was to delineate conditions under which these theories are valid for both flat and twisted wings and to explore the use of empirical methods to correct the theoretical methods where theory is deficient.

1071. MANRO, M. E.; MANNING, K. J. R.; HALLSTAFF, T. H.; ROGERS, J. T.: **Transonic pressure measurements and comparison of theory to experiment for an arrow-wing configuration. Volume 2: Experimental data report, effects of control surface deflection.**: NASA-CR-132728 D6-42670-3-VOL-2 1975. 76N11035

For abstract, see 76N11034.

11.3 HIGH LIFT DEVICES

1072. COE, P. L., JR.; HUFFMAN, J. K.; FENBERT, J. W.: **Leading-edge deflection optimization for a highly swept arrow wing configuration.**: NASA-TP-1777 L-13820 1980. 81N14974

Tests were also conducted to determine the sensitivity of the lateral stability derivative C sub l sub beta to geometric anhedral. The optimized leading edge deflection was developed by aligning the leading edge with the incoming flow along the entire span. Owing to the spanwise variation of upwash, the resulting optimized leading edge was a smooth, continuously warped surface. For the particular configuration studied, levels of leading edge suction on the order of 90 percent were achieved with the smooth, continuously warped leading edge contour. The results of tests conducted to determine the sensitivity of C sub l sub beta to geometric anhedral indicate values of delta C sub l sub beta/delta T which are in reasonable agreement with estimates provided by simple vortex lattice theories.

1073. COE, P. L., JR.; WESTON, R. P.: **Effects of wing leading-edge deflection on low-speed aerodynamic characteristics of a low-aspect-ratio highly swept arrow-wing configuration** NASA-TP-1434 L-12784 1979. 79N26020

Static force tests were conducted in the Langley V/STOL tunnel at a Reynolds number (based on the mean aerodynamic chord) of about 2.0 x 10 to the 6th power for an angle-of-attack range from about - 10 deg to 17 deg and angles of sideslip of 0 and + or - 5 deg. Limited flow visualization studies were also conducted in order to provide a qualitative assessment of leading-edge upwash characteristics.

11.4 MISCELLANEOUS

1074. PARIKH, P. G.; CHEN, A. W.; YU, N. J.; WYATT, G. H.; TIMAR, T.: **Application of boundary layer control to HSCT low speed configuration** AIAA PAPER 90-3199 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Conference, Dayton, OH, Sept. 17-19, 1990. 13 p. 1990. 90A49103

The feasibility of using boundary layer control (BLC) on a high speed civil transport (HSCT) high lift configuration for low speed performance improvement is studied. The possibility of using a part of the suction system previously designed for cruise laminar flow control (LFC) for low speed BLC mode was explored. A suction scheme for BLC was devised for the HSCT high lift configuration. The extent of the suction regions and levels were determined via panel method based inviscid flow analysis coupled with three-dimensional boundary layer analyses. The compatibility of the BLC suction requirements was assessed, and the modifications necessary to operate the system in both modes of operation, were determined. An assessment of the potential aerodynamic performance improvement resulting from an implementation of the BLC concept compared to an optimized simple flap configuration without BLC was made by an Euler code analysis of the simple flap configuration.

1075. RICE, EDWARD J.; ABBOTT, JOHN M.: **Control of flow separation and mixing by aerodynamic excitation.** NASA-TM-103131 E-5462 NAS 1.15:103131 1990. 90N21733

The recent research in the control of shear flows using unsteady aerodynamic excitation conducted at the NASA Lewis Research Center is reviewed. The program is of a fundamental nature, concentrating on the physics of the unsteady aerodynamic processes. This field of research is a fairly new development with great promise in the areas of enhanced mixing and flow separation control. Enhanced mixing research includes influence of core turbulence, forced pairing of coherent structures, and saturation of mixing enhancement. Separation flow control studies included are for a two-dimensional diffuser, conical diffusers, and single airfoils. Ultimate applications include aircraft engine inlet flow control at high angle of attack, wide angle diffusers, highly loaded airfoils as in turbomachinery, and ejector/suppressor nozzles for the supersonic transport. An argument involving the Coanda Effect is made that all of the above mentioned application areas really only involve forms of shear layer mixing enhancement. The program also includes the development of practical excitation devices.

1076. DUTTON, J. C.; CARROLL, B. F.: **Numerical and experimental investigation of multiple shock wave/turbulent boundary layer interactions in a rectangular duct.** AD-A190772 UILU-ENG-88-4001 1988. 88N22320

Multiple shock wave/turbulent boundary layer interactions in constant or nearly constant area supersonic duct flows occur in a variety of devices including scramjet inlets, gas ejectors, and supersonic wind tunnels. For sufficiently high duct exit pressures, a multiple shock wave/turbulent boundary layer interaction or shock train may form in the duct and cause a highly nonuniform, and possibly unsteady, flow at the duct exit. In this report, the mean flow characteristics of two shock train interactions, one with an initial Mach number of 2.5 the other at Mach 1.6, are investigated using spark Schlieren photography, surface oil flow visualization, and mean wall pressure measurements. The Mach 2.5 interaction was oblique and asymmetric in nature. A large separation occurs after the first oblique shock. The top and bottom wall boundary layer separation has been investigated, revealing that the shape of the reattachment lines and surface flow patterns for the two separation regions are quite different. This oblique shock flow pattern occurs in a neurally stable fashion with each type of opposing separation region alternately existing on either the top or bottom wall during the course of a run. A small scale unsteadiness in the shock train location, with movement on the order of a boundary layer thickness, is also observed.

1077. VOLKOV, V. F.; DEMYANENKO, V. S.; DERUNOV, Y. K.; BRODETSKIY, M. D.; RAFAELYANTS, A. A.: **Aerodynamic interference in flow past three dimensional bodies (selected articles).** AD-B102475L FTD-ID(RS)T-1261-85 1986. 87X70009 **US GOV AGENCIES**

1078. MEAUZE, G.: **Shock boundary-layer interaction.** Thermodynamics and fluid mechanics of turbomachinery. Volume 1 (86A29376 12-02). Dordrecht, Martinus Nijhoff Publishers, 1985, p. 433-463. 86A29387

The consequences of the considered shock boundary-layer interaction phenomenon are very important, in particular, in the case of an occurrence of separation. The general characteristics of the mechanisms of shock boundary-layer interaction are discussed, taking into account shock boundary-layer interactions in air-intakes, shock boundary-layer interactions in compressor cascades, shock boundary-layer interaction in nozzles, a transonic shock boundary-layer interaction without separation, supersonic shock reflection without separation, the boundary-layer height corresponding to a sonic Mach number, and the viscosity effect. Attention is also given to the interaction properties and the interaction length in transonic flow without separation, and shock boundary-layer coupling applications.

1079. MARCONI, F.: **The supersonic flow in conical corners.** 1981. 82N10003

A computational procedure was developed to predict the inviscid super hypersonic flow field of conical internal corners. The prediction of internal corner flow fields can be important in the design of supersonic box type inlets. The computational procedure utilizes a second order finite difference marching technique to asymptote to the conical corner flow solution of Euler's equations. These flow fields are dominated by complex shock interactions. All discontinuities, shocks and slip surfaces, are fitted with the appropriate jump conditions. The triple points (the interaction of three shocks and a slip surface) are also computed exactly. Computed results are compared with experimental data and the computational result of other investigations. In addition, the sensitivity of these flow fields to a number of geometric parameters is studied, and the impact of these flows on inlet performance is assessed.

1080. TRIMPI, R. L.: **Modern fluid dynamics of supersonic and hypersonic flight**. AIAA PAPER 80-0862 American Institute of Aeronautics and Astronautics, International Meeting and Technical Display on Global Technology 2000, Baltimore, Md., May 6-8, 1980, 37 p. 80A33275

Many aspects of fluid dynamics impacting supersonic and hypersonic flight are examined. Progress, current problem areas, and prognostications for the future are discussed, with special emphasis on those fluid dynamics facets which can be more directly tied to a potential end-product vehicle. Numerous illustrative examples are included.

1081. BANTLE, JEFFREY WALTER: **Analysis of the interference effects between two Sears-Haack bodies at Mach 2.7**. NASA-CR-184996 NAS 1.26:184996 1982. 89N70806

1082. Survey of models for shock and shock/boundary layer interaction loss prediction. 1981. 82N17187

The calculation of the shock losses has to take into account the losses due to normal shocks as well as the additional losses caused by the shock/boundary layer interaction. Due to the very complex flow behavior, at present this is only possible by empirical correlations for very simplified assumptions. Therefore, additional effort has to be directed to the practical application of analytical methods and to better understanding of the shock/ boundary layer interaction. Basically, transonic cascades have to be designed in such a way that the shocks are not present or occur at minimum shock Mach number. It seems to be possible that for high subsonic inlet Mach numbers the use of new blading design concepts (i.e., supercritical profiles) can meet the first condition, whereas the second condition of minimal shock Mach numbers was successfully verified by the use of wedge type profiles.

1083. COE, P. L., JR.; HUFFMAN, J. K.: **Influence of optimized leading-edge deflection and geometric anhedral on the low-speed aerodynamic characteristics of a low-aspect-ratio highly swept arrow-wing configuration**. NASA-TM-80083 1979. 79N27095

An investigation conducted in the Langley 7 by 10 foot tunnel to determine the influence of an optimized leading-edge deflection on the low speed aerodynamic performance of a configuration with a low aspect ratio, highly swept wing. The sensitivity of the lateral stability derivative to geometric anhedral was also studied. The optimized leading edge deflection was developed by aligning the leading edge with the incoming flow along the entire span. Owing to spanwise variation of upwash, the resulting optimized leading edge was a smooth, continuously warped surface for which the deflection varied from 16 deg at the side of body to 50 deg at the wing tip. For the particular configuration studied, levels of leading-edge suction on the order of 90 percent were achieved. The results of tests conducted to determine the sensitivity of the lateral stability derivative to geometric anhedral indicate values which are in reasonable agreement with estimates provided by simple vortex-lattice theories.

1084. KULFAN, R. M.; YOSHIHARA, H.; LORD, B. J.; FRIEBEL, G. O.: **Application of supersonic favorable aerodynamic interference to fighter type aircraft.** AD-B029985LAFFDL-TR-78-33D180-24059-1 1978. 85X73061 US GOV AGENCIES

1085. KULFAN, R. M.: **Application of hypersonic favorable aerodynamic interference concepts to supersonic aircraft**. AIAA PAPER 78-1458 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Conference, Los Angeles, Calif., Aug. 21-23, 1978, 28 p. 1978. 78A52042

A study was made to identify hypersonic favorable aerodynamic interference concepts for application to supersonic aircraft. Preliminary aerodynamic analysis defined key design parameters, and scoped potential aerodynamic efficiency improvements. The study included supersonic biplanes, ring wings, parasol wings, wave rider concepts, and flat-top wing/body arrangements. Results indicate the parasol wing concept offers the greatest potential aerodynamic benefits for the study conditions. However, the best aerodynamic concept is very dependent on the design Mach number, and on the airplane component size relationships. It is shown that existing aerodynamic design/analysis methods can be used for parasol wing aerodynamics studies.

1086. RADKEY, R. L.; WELGE, H. R.; FELIX, J. E. **Aerodynamic characteristics of a Mach 2.2 advanced supersonic cruise aircraft configuration at Mach numbers from 0.5 to 2.4.** NASA-CR-145094 MDC-J4558 1977. 77X10013 US GOV AGENCIES AND CONTRACTORS

Wind tunnel tests were conducted on an advanced supersonic cruise aircraft model. Numerous technology problems associated with the design and analysis of supersonic cruise aircraft were explored to create a Mach

2.2 design information data base. The test addressed the validity of design and analysis methods as applied to arrow wing configurations, problems of wing reflexing to achieve beneficial wing-nacelle interference, and the possibility of using an external compression inlet rather than a mixed compression inlet at Mach 2.2. Configuration longitudinal and lateral-directional aerodynamic characteristics were determined, and pressure (247 ports) were taken simultaneously with the force data. Tuft and schlieren pictures were also taken.

12.0 SUPERSONIC AIRCRAFT DESIGNS

12.1 CONCORDE

1087. LAVIEC, G.; GANLEY, G.: **The Rolls Royce/SNECMA Olympus 593 engine operational experience and the lessons learned** IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 73-80. 1990. 91A10958

A review of the 13 years of Concorde engine design and development are presented. Particular attention is devoted to the reliability aspects of this engine running in very severe ambient conditions as compared to a conventional subsonic engine. Specific operational requirements called for an engine to produce sufficient thrust to takeoff with 11 tons of payload for a distance of 3500 nm at Mach 2. To achieve this goal it became necessary to add an afterburner to a conventional twin spool engine and to add a variable secondary nozzle and a thrust reverser. An electronic analog fuel control system was adopted to control the engine to the required turbine inlet temperature appropriate to the thrust required while ensuring that all limitations are not exceeded and that crew handling be minimal. Details and graphs are presented for engine operational experience covering utilization rates, shop visit rates, inflight shutdowns, and the effects of supersonic operations.

1088. MACDONALD, DAVID A.: **British Airways operational experience with Concorde** IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 90-94. 1990. 91A10960

Since 1976 British Airways has operated Concorde aircraft on a variety of routes. During that period more supersonic operating experience than any other organization has been accumulated, to a total of more than 80,000 flying hours. The key to Concorde's success, however, has been in the marketplace where its unique capabilities have ensured a niche against which there is currently no real competition. With thirty four scheduled and many charter services operated each week perhaps the greatest challenge will be maintaining the integrity of operation as the aircraft progresses into the later stages of its life.

1089. CORMERY, G.: **Concorde - 1958-1975** IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 58-65. 1990. 91A10956

An overview of Concorde research, design, and development evolution is presented. The various airframe geometries considered for attaining a Mach 2.2 max cruise limit imposed by various temperature limitations are described. Final selection of a delta wing plus a foreplane resulted after a number of wing, fuselage and empennage combinations were evaluated. Other areas requiring advanced research and design that had to be solved included: jet engine type selection, number and positioning, visibility problems in landing and takeoff attitudes that led to adoption of the droop nose, systems integration with particular regard to flight controls and the automatic flight control system, and the evolution of the air intake system to accommodate operation over the entire flight envelope. Finally, a general assessment of Concorde commercial operation is presented.

1090. SWADLING, S. J.: **Commercial supersonic operations** Thirteen years of experience with Concorde IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 66-71. 1990. 91A10957

This paper is intended to give a brief overview of Concorde in-service operations as viewed by the manufacturer. It identifies the features peculiar to Concorde as a supersonic transport and problems and major incidents encountered during development flying and operation. Finally it covers in-service experience and identifies the most troublesome items.

1091. KLEITZ, PIERRE: **Twenty years of Concorde - The experience of Air France**. IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 85-89. In French. 1990. 91A10959

The technical, commercial and economic aspects of Air France's operational experience with the Concorde are presented. From the technical point of view engine reliability from both the operational and maintenance aspects is less than that for conventional aircraft though dispatch reliability has been satisfactory. Fuel consumption and total operating cost have been high however, some commercial profitability has been achieved. Specific noise abatement procedures in supersonic flight and around airports forced severe operational restrictions including subsonic cruise limitations over populated areas. It is concluded that the Concorde experience has resulted in valuable operational and technical experience that will prove useful in future SST commercial transport designs.

1092. FORESTIER, J.; LECOMTE, P.; POISSON-QUINTON, PH.: **Supersonic air transport programs in the 60's**. IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 14-29. In French. 1990. 91A10952

A review of the SST programs conducted by the United States, France, Great Britain and the USSR during the 1960s is presented. The designs that evolved considered such questions as the supersonic boom and other noise related problems that were directly related to environmental and public opinion issues. Development of the Concorde program is discussed, and a brief outline of the TU 144 project and the discontinued U.S. SST competition is presented. Some aspects of initial Concorde operational problems are also described.

1093. LEYMAN, C. S.: **A review of the technical development of Concorde.** Progress in Aerospace Sciences (ISSN 0376-0421), vol. 23, no. 3, 1986, p. 185-238. 1986. 87A16408

The technical problems encountered during the development and certification of Concorde are reviewed. The topics covered are mainly associated with aerodynamics, but other areas are discussed where they interact with the aerodynamic design or if there were conditions peculiar to supersonic transportation which had to be considered.

1094. SWADLING, S. J.: **Commercial supersonic operations -Ten years of experience with Concorde.** SAE PAPER 861683 SAE, Aerospace Technology Conference and Exposition, Long Beach, CA, Oct. 13-16, 1986. 10 p. 87A32599

This paper is intended to give a brief overview of Concorde development and in-service operations to date. It identifies the features peculiar to Concorde as a supersonic transport and the various problems and major incidents encountered

1095. RECH, J.; LEYMAN, C. S.: **Concorde aerodynamics and associated systems development.** New York, American Institute of Aeronautics and Astronautics, Inc., 1980. 104 p 81A16718

A case study on the innovative aspects of Concorde aerodynamics is presented. Attention is given to design objectives, aircraft aerodynamic layout, flying qualities, performance and noise, and powerplant aerodynamics.

1096. COLLARD, D.: **Synthesis of test results obtained with Concorde at high incidences**. AAAF-NT-80-26 ISBN-2-7170-0622-2 1980. 81N12079

The lift experienced by Concorde continues to increase uniformly up to an angle of incidence of thirty five degrees. A change in flow characteristics over the airfoil occurs at an angle of twenty two degrees. The consequences of this phenomenon on the aircraft's flight behavior are studied. Most of the results were obtained in wind tunnel experiments with series aircraft models. Comparisons are also made between some in flight and wind tunnel test results. It is concluded that relatively minor changes in the shape of the airfoil can have extremely important effects on aircraft flight behavior.

1097. LEYMAN, C. S.: **Concorde with the airlines**. In NASA Langley Research Center Supersonic Cruise Res., 1979, Pt. 2, p 741-757 (See 81N18005 09-01) 1980. 81N18013

The only supersonic aircraft in airline service, Concorde, offers the first actual test of supersonic cruise feasibility and the only real experience relative to passenger, airline,

and community acceptance. The dominant characteristic of Concorde operations is low aircraft utilization, due partly to the restricted route network. Operating costs, the maintenance/reliability record and associated dispatch delays are discussed. Problems with overwater operations, and the secondary boom phenomena are examined. Monthly average load factors for various routes, major causes of technical delays, aircraft technical performance, and aircraft tracks are graphically depicted.

1098. Results of an opinion survey concerning the limited operations of the Concorde supersonic airplane at Dulles International Airport. 1976. 80N72690

1099. COLLARD, D.: **Synthesis of test results on the Concorde at high angle of attack**. AAAF PAPER NT 80-26 Association Aeronautique et Astronautique de France, Colloque d'Aerodynamique Appliquee, 16th, Lille, France, Nov. 13-15, 1979, 13 p. In French. 80A36854

Results of wind tunnel tests and flight tests on the Concorde at high angle of attack are presented. It is shown that lift continues to increase more or less uniformly to an angle of attack (alpha) of 35 deg. However, at alpha equals 22 deg the character of the flow over the wing changes; this change causes pitch-up, an advancement of the aerodynamic center, and sideslip of the advancing wing. This change also leads to a progressive deterioration of elevon efficiency and to a decrease of lateral stability.Visualization results of flow on the upper surfaces of the wings are presented and used to study the development of vortices as a function of angle of attack. Test results on prototype aircraft are compared with those on production models.

1100. BROWN, T. W.; TALBOT, J. E.: **Powerplant integration - The application of current experience to future developments**. ASME PAPER 78-GT-113 American Society of Mechanical Engineers, Gas Turbine Conference and Products Show, London, England, Apr. 9-13, 1978, 11 p. 1978. 79A10788

The paper reviews the basic operation and function of the current Concorde powerplant and describes some advances in aerodynamic and control system philosophy for better performance with reduced weight and complexity. The discussion is limited to air intake design and powerplant control. With low-risk aerodynamic modifications to provide enhanced performance, the current twin-nacelle unit can be improved to give overall characteristics at full scale within an acceptable margin of current proposals for so-called advanced supersonic transport aircraft. In the future, any alternative proposals for a powerplant installation must show a significant margin in terms of theoretical/wind tunnel performance before it can be recognized as a viable alternative.

1101. COOMBE, T. W.; GOLDSMITH, H. A.; MORRISS, D. P.: **Aerodynamic/structural interactions in the design of the Concorde nacelle.**: Association Aeronautique et Astronautique de France and Union Syndicale des Industries Aeronautiques et Spatiales, Congres International Aeronautique, 11th, Ecole Nationale Superieure de Techniques Avancees, Paris, France, May 21-23, 1973, Paper. 36 p. 74A25364

This paper examines the overall design of the Concorde nacelle from the point of view of the interaction of aerodynamic and structural requirements. It is shown that in general the influence of aerodynamics has been dominant, with the structure having to conform to the aerodynamic requirements as efficiently as possible. However, in some areas structural and weight considerations have played a major part.

1102. BRASSUER, J. M., and LEYNAERT, J.; **Aerodynamic design of Mach 2 supersonic transports - Air intake system**. NASA-TT-F-8441, 1963. 63X14627

12.2 TUPOLEV TU-144

1103. FORESTIER, J.; LECOMTE, P.; POISSON-QUINTON, PH.: **Supersonic air transport programs in the 60's**. IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 14-29. In French. 1990. 91A10952

A review of the SST programs conducted by the United States, France, Great Britain and the USSR during the 1960s is presented. The designs that evolved considered such questions as the supersonic boom and other noise related problems that were directly related to environmental and public opinion issues. Development of the Concorde program is discussed, and a brief outline of the TU 144 project and the discontinued U.S. SST competition is presented. Some aspects of initial Concorde operational problems are also described.

1104. MOON, HOWARD: **Soviet SST: The technopolitics of the Tupolev-144**. New York, Orion Books, 1989, 288 p. 89A42947

The history of the unsuccessful Soviet effort to develop an SST aircraft, the TU-144, is recalled, considering both political and technological aspects. Consideration is given to the relationship between the designer Tupolev and the Soviet state, the TU-104 and TU-114, the international competition in SST development beginning in the late 1950s, reports of SST espionage, the 1969 TU-144 prototype and comparisons with the Concorde, engines and internal and external aerodynamics, and radical changes in the 1972 production model. Also discussed are the catastrophic crash of the production model, much slower progress during 1973-1977, the apparent second crash of 1978, and the final role of the TU-144 as a bomber testbed and record-setter.

12.3 B-2707

1105. TINOCO, E. N.; JOHNSON, F. T.; FREEMAN, L. M.: **Application of a higher order panel method to realistic supersonic configurations**. AIAA PAPER 79-0274 (American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 17th, New Orleans, La., Jan. 15-17, 1979) Journal of Aircraft, vol. 17, Jan. 1980,p. 38-44. 80A17696

A higher-order panel method has been developed for the analysis of linearized subsonic and supersonic flow over configurations of general shape. This method overcomes many of the slender body limitations of present day programs in the analysis of supersonic configurations. The capabilities of this method are demonstrated through its application to the analysis of realistic supersonic cruise configurations. Comparisons are shown with experimental data and with results from other methods in current use. These comparisons demonstrate the unique capabilities of a major new software system called PAN AIR soon to be available as a general boundary value problem solver.

1106. SWAN, W. C.: **Design evolution of the Boeing 2707-300 supersonic transport. Part 1: Configuration development, aerodynamics, propulsion, and structures**. In AGARD Aircraft Design Integration and Optimization, Vol. 1 18 p (SEE 74N31458 21-02). 1974. 74N31467

The design activities involved in developing the Boeing 2707 supersonic transport aircraft are discussed. The history of the design activity is presented to show areas where failure and/or misconception occurred due to insufficient knowledge and to show how the shortcomings were corrected or avoided in subsequent configuration evaluations. Emphasis is placed on selected areas where preliminary design tools could be improved. The various design configurations are illustrated and their technical features are analyzed. The structural design features of various components are described and illustrated. The operational objectives on which the preliminary planning was based are defined. The functions of specific segments of the organization are reported.

12.4 XB-70

1107. LEE, PAI-HUNG; LAN, C. EDWARD; MUIRHEAD, VINCENT U.: **Experimental investigation of dynamic ground effect**. Journal of Aircraft (ISSN 0021-8669), vol. 26, June 1989, p. 497, 498. Previously announced in STAR as 88N12458. 89A39185

A 60-degree delta wing, an F-106B, and an XB-70 model with and without flap deflections were tested in static and dynamic ground effect in the 36-by-51-inch subsonic wind tunnel at the University of Kansas. Dynamic ground effect was measured with movable sting support. For flow visualization, a tufted wire grid was mounted on the movable sting behind the model. Test results showed that lift and drag increments in dynamic ground effect were always lower than static values. Effect of the trailing edge flap deflections on lift increments was slight. The fuselage reduced the lift increments at a given ground height. From flow visualization under static conditions, the vortex core was seen to enlarge as the ground was approached.

1108. PETERSON, J. B., JR.: **Wind-tunnel/flight correlation program on XB-70-1**. In its Wind-Tunnel/Flight Correlation, 1981, p 65-91 (See 82N25196 16-02) 1982. 82N25201

The XB-70-1 was selected for a wind-tunnel/flight correlation program as representative of a large, flexible supersonic airplane similar to a supersonic transport. Tests were made to determine the effects of control deflections, wing tip deflection, and variations in inlet mass flow (additive drag).

1109. PETERSON, J. B., JR.; MANN, M. J.; SORRELLS, R. B., III; SAWYER, W. C.; FULLER, D. E.: **Wind-tunnel/flight correlation study of aerodynamic characteristics of a large flexible supersonic cruise airplane (XB-701) 2: Extrapolation of wind-tunnel data to full-scale conditions**. NASA-TP-1515 L-12688 1980. 80N16032

The results of calculations necessary to extrapolate performance data on an XB-70-1 wind tunnel model to full scale at Mach numbers from 0.76 to 2.53 are presented. The extrapolation was part of a joint program to evaluate performance prediction techniques for large flexible supersonic airplanes similar to a supersonic transport. The extrapolation procedure included: interpolation of the wind tunnel data at the specific conditions of the flight test points; determination of the drag increments to be applied to the wind tunnel data, such as spillage drag, boundary layer trip drag, and skin friction increments; and estimates of the drag items not represented on the wind tunnel model, such as bypass doors, roughness,protuberances, and leakage drag. In addition, estimates of the effects of flexibility of the airplane were determined.

1110. ARNAIZ, H. H.; PETERSON, J. B., JR.; DAUGHERTY, J. C.: **Wind-tunnel/flight correlation study of aerodynamic characteristics of a large flexible supersonic cruise airplane (XB-70-1). 3: A comparison between characteristics predicted from wind-tunnel measurements and those measured in flight**. NASA-TP-1516 H-1079 1980. 80N17986

A program was undertaken by NASA to evaluate the accuracy of a method for predicting the aerodynamic characteristics of large supersonic cruise airplanes. This program compared predicted and flight-measured lift, drag,angle of attack, and control surface deflection for the XB-70-1 airplane for 14 flight conditions with a Mach number range from 0.76 to 2.56. The predictions were derived from the wind-tunnel test data of a 0.03-scale model of the XB-70-1 airplane fabricated to represent the aeroelastically deformed shape at a 2.5 Mach number cruise condition. Corrections for shape variations at the other Mach numbers were included in the prediction. For most cases, differences between predicted and measured values were within the accuracy of the comparison. However, there were significant differences at transonic Mach numbers. At a Mach number of 1.06 differences were as large as 27 percent in the drag coefficients and 20 deg in the elevator deflections. A brief analysis indicated that a significant part of the difference between drag coefficients was due to the incorrect prediction of the control surface deflection required to trim the airplane.

1111. DAUGHERTY, J. C.: **Wind-tunnel/flight correlation study of aerodynamic characteristics of a large flexible supersonic cruise airplane CXB-70-1). 1: Wind-tunnel tests of a 0.03-scale model at Mach numbers from 0.6 to 2.53**. NASA-TP-1514 A-7712 1979. 80N11068

The longitudinal and lateral forces and moments for a 0.03 scale deformed rigid, static force model of the XB-70-1 airplane were determined. Control effectiveness was determined for the elevon in pitch and roll, for the canard, and for the rudders. Component effects of the canard, deflected with tips, variable position canopy, bypass doors, and bleed dump fairing were measured. The effects of small variations in inlet mass flow ratio and small amounts of asymmetric deflection of the wing tips were assessed.

12.5 B-58

1112. GUTHRIE, J. A.; LIGON, J. B.: **Flight testing the Hustler500**. Society of Flight Test Engineers, Annual Symposium, 12th, Dayton, OH, September 16-18, 1981, Proceedings (83A32926 14-01). Lancaster, CA, Society of Flight Test Engineers, 1981, p. 6-1 to 6-22. 1981. 83A32930

Test techniques and results of an evaluation of the Hustler 500 aircraft are presented. The aircraft itself and its instrumentation is described. The results of takeoff and landing tests, pitot static calibration, and drag polar determination are addressed. Temperature-limited torque values for various altitudes are shown, as are the excess thrust curves, climb performance, and VFR range capabilities. The results for stability and control tests are given, including longitudinal static stability, maneuvering static stability, lateral-directional stability, roll power, Dutch roll, short period, phugoid mode and trim changes. The results for stalls and flutter envelope expansion are also shown. Pilot comments with respect to the cockpit, ground handling, takeoff, and landing are presented, and the conclusions and recommendations of the tester are stated.

12.6 SR-71 / YF-12

1113. GREY, R. P.; NELSON, R. L.; MEYER, J. E.: **SR-71 digital automatic flight and inlet control system.** SAE PAPER 851977 IN: Aerospace Behavioral Engineering Technology Conference, 4th, Long Beach, CA, October 14-17, 1985, Proceedings (86A35426 15-54). Warrendale,PA, Society of Automotive Engineers, Inc., 1985, p. 399-410. 86A35457

This paper presents a description and treats the integration of a new triple channel multi-rate Digital Automatic Flight and Inlet Control System (DAFICS) into the SR-71 aircraft. Predicted airframe longevity to the year 2000 and aging automatic flight control/air inlet control analog systems dictated a modernization program to insure supportability over the life span of the aircraft. Aerodynamic consideration and development rationale is provided. A functional system description identifies the systems being replaced. Simulation, hardware/software development, redundancy management and flight experience is

1114. BAUER, C. A.; MACKALL, K. G.; STOLL, F.; TREMBACK, J. W.: **Comparison of flight and wind tunnel model instantaneous distortion data from a mixed-compression inlet (U).**: NASA-TM-81362 Sept. 1981 82X10037 <u>US GOV AGENCIES AND CONTRACTORS</u>

Data from a mixed-compression inlet on a YF-12C airplane were compared with data obtained from both a full-scale and a one-third-scale wind tunnel model of the same inlet, all operating at nearly identical test conditions for two supersonic Mach numbers. Steady-state and instantaneous values of radial, circumferential, and maximum-minus-minimum distortion descriptors were used for the analysis. Strouhal number scaling techniques were used. Although steady-state distortion levels were sometimes significantly different, a linear relationship existed between the maximum value of instantaneous distortion and the steady-state distortion value. This relationship was independent of both the inlet and the test condition and was valid for both flight and wind tunnel model data. As a result, the maximum in-flight value of instantaneous distortion can be predicted within + or - 10 percent. Inlet turbulence levels on all three inlets agreed well at each test condition. This indicates that the inlet turbulence level measured on wind tunnel models is representative of that measured in flight.

1115. BANGERT, L. H.; FELTZ, E. P.; GODBY, L. A.; MILLER, L. D.: **Aerodynamic and acoustic behavior of a YF-12 inlet at static conditions.** AIAA PAPER 81-1597 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 10 p. NASA-supported research. 81A40972

An aeroacoustic test program was performed with a YF-12 aircraft at groundstatic conditions. The objective was to collect acoustic and aerodynamic data that could determine the cause of YF-12 inlet noise suppression observed earlier. The results showed that the far-field noise level was lower with the YF-12 inlet than with a bellmouth inlet at engine speeds above 5500 rpm. The differences were about 5 PNdB to 11 PNdB, depending on YF-12 inlet configuration and on engine speed. Measurements showed that YF-12 inlet noise suppression was not caused by flow choking. The spike support struts were probably responsible, as in that region the spectral peak near the blade passing frequency disappeared between 6000 and 6600 rpm, and multiple pure tones were greatly reduced.

1116. BANGERT, L. H.; FELTZ, E. P.; GODBY, L. A.; MILLER, L. D.: **Aerodynamic and acoustic behavior of a YF-12 inlet at static conditions.** NASA-CR-163106 LR-29623 1981. 81N21079

An aeroacoustic test program to determine the cause of YF-12 inlet noise suppression was performed with a YF-12 aircraft at ground static conditions. Data obtained over a wide range of engine speeds and inlet configurations are reported. Acoustic measurements were made in the far field and aerodynamic and acoustic measurements were made inside the inlet. The J-58 test engine was removed from the aircraft and tested separately with a bellmouth inlet. The far field noise level was significantly lower for the YF-12 inlet than for the bellmouth inlet at engine speeds above 5500 rpm. There was no evidence that noise suppression was caused by flow choking. Multiple pure tones were reduced and the spectral peak near the blade passing frequency disappeared in the region of the spike support struts

1117. BANGERT, L. H.; BURCHAM, F. W., JR.; MACKALL, K. G.: **YF-12 inlet suppression of compressor noise - First results.** AIAA PAPER 80-0099 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 8 p. NASA-supported research. 80A34537

An aeroacoustic test program was performed with a YF-12 aircraft at ground-static conditions. The objective was to collect acoustic and aerodynamic data that could determine the cause of inlet noise suppression observed earlier. The first results of the test program are presented here. There was no indication that the flow was close to choking. The data indicated significant reduction in sound pressure level (SPL) across the strut and bypass region at frequencies near the blade passing. Far-field data showed that the maximum sound pressure level near the blade-passing frequency was at zero degrees from the inlet centerline.

1118. RICH, B. R.: **Sixteen years of Mach 3 flight**. Interavia, vol. 35, July 1980, p. 636, 637. 80A42575

Experience, dating back to the early 1960s, with the high-supersonic, high-altitude operations of the YF-12/SR-71 Blackbird aircraft is reviewed. Future prospects for the development of SST aircraft in the United States are also considered; problems of Mach 3 flight are discussed.

1119. ANDERSON, D. L.; CONNOLLY, G. F.; MAURO, F. M.; REUKAUF, P. J.; MARKS, R.: **YF-12 cooperative airframe/propulsion control system program, volume 1**. NASA-CR-163099 SP-5317 H-1136 1980. 81N13044

Several YF-12C airplane analog control systems were converted to a digital system. Included were the air data computer, autopilot, inlet control system, and auto throttle systems. This conversion was performed to allow assessment of digital technology applications to supersonic cruise aircraft. The digital system was composed of a digital computer and specialized interface unit. A large scale mathematical simulation of the airplane was used for integration testing and servocontrol.

1120. SCHWEIKHARD, W. G.; CAMPBELL, D. H.: **An introduction and summary of the YF-12 propulsion research program** (U) 1978. 79X72835 US GOV AGENCIES

1121. ALBERS, J. A.: **Status of the NASA YF-12 propulsion research program.** NASA-TM-X-56039 H-935 1976. 76N19152

The YF-12 research program was initiated to establish a technology base for the design of an efficient propulsion system for supersonic cruise aircraft. The major technology areas under investigation in this program are inlet design analysis, propulsion system steady-state performance, propulsion system dynamic performance, inlet and engine control systems, and airframe/propulsion system interactions. The objectives, technical approach, and status of the YF-12 propulsion program are discussed. Also discussed are the results obtained to date by the NASA Ames, Lewis, and Dryden research centers. The expected technical results and proposed future programs are also given. Propulsion system configurations are shown.

1122. ALBERS, J. A.; OLINGER, F. V.: **YF-12 propulsion research program and results.** In its Proc. of the SCAR Conf., Part 1, p 417-456 (See 77N17996 09-01) 1976. 77N18017

The objectives and status of the propulsion program, along with the results acquired in the various technology areas, are discussed. The instrumentation requirements for and experience with flight testing the propulsion systems at high supersonic cruise are reported. Propulsion system performance differences between wind tunnel and flight are given. The effects of high frequency flow fluctuations (transients) on the stability of the propulsion system are described, and shock position control is evaluated.

12.7 B-1

1123. STANDLEY, KENT: **B-1B performance flight test follow-on evaluation**. AD-B139107L AFFTC-TR-89-42 1989. 90X71356 US GOV AGENCIES AND CONTRACTORS

1124. GOLDSMITH, E. L.; MCGREGOR, I.: **The effect of intake geometry changes on the internal performance of a rectangular pitot intake on the side of a fuselage. Part 1: Subsonic and transonic speeds.**: RAE-TR-88070-PT-1 BR111920-PT-1 Nov. 1988 90X70642 US GOV AGENCIES AND CONTRACTORS

This report contains information on flow distribution, inlet pressure, intake systems, pressure distribution, pressure recovery, flow distortion, flow geometry, mass flow rate, slideslip, subsonic and transonic speeds.

1125. NEWSOM, WILLIAM A., JR.; GRAFTON, SUE B.: **Free-flight investigation of a 1/17-scale model of the B-1 airplane at high angles of attack.** NASA-TM-SX-2744 L-8762 AF-AM-128 1973. 88X72371 US GOV AGENCIES AND CONTRACTORS

1126. MACMILLER, C. J.; HAAGENSON, W. R.: **Unsteady inlet distortion characteristics with the B-1B.** In AGARD Engine Response to Distorted Inflow Conditions, 17 p (See 87N24464 18-07) March 1987 87N24478

An extensive wind tunnel and flight test program was conducted to verify inlet performance and distortion characteristics on the B-1B aircraft. During the course of these investigations, several unsteady, total-pressure disturbances at various discrete frequencies were encountered: (1) inlet duct resonance at low power settings; (2) environmental control system (ECS) precooler duct resonance; and (3) nose gear wake ingestion. This resulted in the need to quantify these effects and assess the impact on engine stability characteristics. As a result, engine control features were modified, and aircraft configuration changes were implemented. Results and findings of these investigations are summarized.

1127. BERGMAN, J. C.: **Linear regression models of B-1B and F-16 inlet performance parameters.** AD-B096816L 1985. 86X72427 US GOV AGENCIES

1128. BURCHFIELD, C. G.: **Aerodynamic force and pressure measurements on a 0.06-scale B-1B aircraft model at Mach numbers from 0.60 to 1.20.** AD-B095350L AEDC-TSR-83-P28 1983. 86X70984 US GOV AGENCIES

1129. RIDDELL, J. F.: **Performance characteristics of a 0.20-scale B-1B inlet verification model (Phase 2) at mach numbers from 0 to 1.2.** AD-B084953L AD-E001667 AEDC-TSR-84-P14 1984. 84X78949 US GOV AGENCIES AND CONTRACTORS

1130. RIDDELL, J. F.: **Performance characteristics of a 0.20-scale B-1B inlet verification model (Phase 2) at mach numbers from 0 to 1.2.** AD-B084953L AD-E001667 AEDC-TSR-84-P14 June 1984 84X78949 US GOV AGENCIES AND CONTRACTORS

This report contains information on aerodynamic characteristics, B-1 aircraft, engine inlets, jet engines, nacelles, scale models, wind tunnel tests, distortion, doors, ducts, external stores, flaps control surfaces), flowmeters, Mach number, pressure measurement, subsonic and transonic flow.

1131. SPURLIN, C. J.: **Force and pressure measurements on 0.06-scale B-1 and B-1B models at Mach numbers from 0.60 to 1.20.** AD-B067874L AEDC-TSR-82-P17 1982. 83X71049 US GOV AGENCIES

1132. HOELEN, F. J.: **B-1 Inlet and Nozzle Flight Performance Determination program.** AIAA PAPER 81-1852 American Institute of Aeronautics and Astronautics, Atmospheric Flight Mechanics Conference, Albuquerque, NM, Aug. 19-21, 1981, 7 p., USAF-sponsored research. 82A13981

The B-1 Inlet and Nozzle Flight Performance Determination program was part of an overall USAF research program for the improvement of installed inlet and nozzle performance prediction techniques. Data were acquired by adding external surface pressure instrumentation in the region of the left inlet and aft nacelle of a B-1 aircraft by and instrumenting three B-1 wind tunnel models like the aircraft and conducting wind tunnel tests at conditions matching the flight-test points. Wind tunnel and flight-test data were correlated in the transonic range. Comparisons of model and aircraft inlet and aft nacelle drags derived from pressure area integration are presented. Results show that the 0.06 scale model aft nacelle drags are three to eleven drag counts higher than those of the aircraft with approximately parallel data trends. The inlet model drags were also higher than those of the aircraft, and data trends were again parallel. The 0.07 scale inlet model ramp drag was three drag counts higher than aircraft values, while cowl drags were as much as eight counts higher in the subsonic portion of the transonic range.

1133. KUTSCHENREUTER, P. H., JR.; MOORE, M. T.; BURNETT, G. A.: **Large scale inlet distortion investigation.**: AFFDL-TR-70-20 May 1970 82X73443 US GOV AGENCIES

This report contains information on dynamic characteristics, engine inlets, flow distortion, inlet pressure, pressure recovery, steady state, boundary layer control, cowlings, engine design, frequency division multiplexing, performance tests, turbofan engines, and wind tunnel tests.

1134. SCHOENHEIT, A. E.; KARGER, W. J.: **Aerodynamic integration of externally mounted engines on a long-range bomber**. AIAA PAPER 81-1693 American Institute of Aeronautics and Astronautics, Aircraft Systems and Technology Conference, Dayton, OH, Aug. 11-13, 1981, 9 p. 81A44899

The B-1 strategic bomber was designed as a multimission variable-sweep weapon system. The diverse aerodynamic requirements of integrating the propulsion system into both an efficient subsonic cruising vehicle and a penetrating subsonic and supersonic weapon system have been achieved. The design process included numerous wind tunnel tests to refine the engine inlet and nozzle characteristics as well as integration of the nacelle package into the overall configuration.

1135. SCHIBMA, R. A.; WEGNER, E. D.: **The evolution of a strategic bomber**. AIAA PAPER 81-0919 American Institute of Aeronautics and Astronautics, Annual Meeting and Technical Display on Frontiers of Achievement, Long Beach, CA, May 12-14, 1981, 11 p. 81A40324

This paper discusses the evolution of a strategic bomber from conceptual formulation studies to flight-test demonstration. The B-1 bomber is used as a specific example of this process. Subjects addressed include formulation of operational and design requirements, design philosophy, design features, interesting design problems encountered, and the resulting air vehicle capability. Also addressed is the B-1 derivative, a multirole bomber, an adaptation to satisfy the versatility of current Department of Defense (DOD) requirement for a Long-Range Combat Aircraft (LRCA).

1136. RIDDELL, J. F.: **Inlet drag characteristics of a 0.07-scale B-1 model at free-stream mach numbers from 0.55 to 1.41.** AD-B039448AEDC-TR-79-19 1979. 80X70541 US GOV AGENCIES

1137. SARGENT, J.; KOSTIN, L.; GILBERTSON, M.: **B-1 wind tunnel test results of 0.06 scale nozzle/afterbody verification model June 1974 test, AEDC TF-336, volume 3.** AD-B043116L NA-75-157-VOL-3 1976. 80X74127 US GOV AGENCIES

1138. SARGENT, J.; KOSTIN, L.; GILBERTSON, M.: **B-1 wind tunnel test results of 0.06 scale nozzle/afterbody verification model June 1974 test, AEDC TF-336, volume 2.** AD-B043115L NA-75-157-VOL-2 1976. 80X74126 US GOV AGENCIES

1139. KELLY, R.: **Analysis of the aerodynamic characteristics of the B-1 aerodynamics force model 4 obtained during Ames test 97-785**. AD-B043096L NA-74-273 1975. 80X73734 US GOV AGENCIES

1140. HUFF, J.; BOMAN, C.: **B-1 full scale inlet engine compatibility test AEDC TF 329 and SF 166. Volume 4. Basic inlet characteristics.** AD-A043239L NA-74-378 1975. 80X72559 US GOV AGENCIES

1141. LEONARD, J.; GILBERTSON, M. W.: **B-1 air vehicle 0.06 scale nozzle/afterbody verification model wind test results test number one, (AEDC SF-150) (AEDC TF-285).** AD-B043098L NA-74-51 1974. 80X72552 US GOV AGENCIES

1142. KELLY, R.; ROBINSON, M. R.: **Analysis of aerodynamic characteristics of the B-1 aerodynamics force model 4 obtained during AEDC tests TF-307 and SF-161, phase 3, volume 1.** AD-B043316L NA-73-502-VOL-1 1974. 80X74125 US GOV AGENCIES

1143. Analysis of aerodynamic characteristics of the B-1 aerodynamics force model 4 obtained during AEDC tests TF-307 and SF-161, phase 3. Volume 2: Appendix. AD-B043317L NA-73-502-VOL-2 1974. 80X74124 US GOV AGENCIES

1144. HARTILL, W. R.: **Test results of an .07 scale B-1 external compression inlet drag model NASA Ames test** (97) 641. AD-B042868L NA-73-125 1973. 80X74523 US GOV AGENCIES

1145. RYNES, D. J.: **Analysis of aerodynamic characteristics of the B-1 Aerodynamic force model 3A obtained during NAAL 650.** AD-B042867L TFD-73-608 1973. 80X74522 US GOV AGENCIES

1146. MACMILLER, C. J.; HURLEY, O. D., III: **B-1 inlet distortion characteristics at air vehicle CDR, 31 May 1973.**: AD-B042866L TFD-73-342 June 1973 80X74128 US GOV AGENCIES

This report contains information on the B-1 aircraft, engine inlets, flow distortion, inlet flow, wind tunnel tests, aircraft models, flight simulators, swept wings, and turbofan engines.

1147. SCHOENHEIT, A. E.; RYNES, D. J.: **Analysis of aerodynamic characteristics of the B-1 aerodynamic force model 3A obtained during AEDC TF-284 and SF149.** AD-B043565L NA-73-370 1973. 80X74161 US GOV AGENCIES

1148. SCHOENHEIT, A. E.; RYNES, D. J.: **Analysis of the aerodynamic characteristics of the B-1 aerodynamic force model 3 obtained during TWT 262.** AD-B043244L TFD-73-1185 1973. 80X74119 US GOV AGENCIES

1149. PETERSON, M. W.: **Summary of test plans for the B-1 full scale inlet/engine compatibility test at AEDC.** AD-B043144L TFD-72-833 1972. 80X72560 US GOV AGENCIES

1150. DARKER, G.: **Chordwise pressure distributions on the B-1 wing panel and hood at M = 2.2.** AD-B042846L TFD-72-1523 1972. 80X74517 US GOV AGENCIES

1151. TIPTON, A. G.; KERN, D. L.: **B-1 jet exhaust noise simulation .10 scale model.** AD-B042849L TFD-72-820 1972. 80X73817 US GOV AGENCIES

1152. MACMILLER, C. J.: **B-1 inlet distortion characteristics at engine CDR 14.**: AD-B043243L TFD-72-766 June 1972 80X73274 US GOV AGENCIES

This report contains information on the B-1 aircraft, engine inlets, turbojet engines, aerodynamics, scale models, vortex generators, and wind tunnel tests.

1153. BROWN, M. A.: **Aerodynamic force data for the .1 scale B-1 escape module in the AEDC supersonic propulsion wind tunnel 16S at Mach numbers 1.7 through 2.4 (AEDC SF148).** AD-B043365L NA-72-181 1972. 80X73733 US GOV AGENCIES

1154. SITAR, D.: **Analysis of low speed aerodynamic characteristics of the 0.036 scale B-1 force model 2 in the NR low speed wind tunnel (NAAL-644).** AD-B043093L NA-71-507 1972. 80X72988 US GOV AGENCIES

1155. GILLINS, R. L.; STILES, R. L.: **Trisonic wind tunnel tests of the B-1 air vehicle 0.036-scale aero force model 3 to investigate nacelle inlet and duct modifications and various empennage configurations in the supersonic region TWT-237.** AD-B043231L NA-71-543 1971. 80X74122 US GOV AGENCIES

1156. SCHOENHEIT, A. E.; ROBINSON, M. R.; WILKIN, C.: **Analysis of the aerodynamic characteristics of the B-1 aerodynamic force model 3 obtained during TWT 234 and TWT 237.** AD-B043318L NA-71-505 1971. 80X74118 US GOV AGENCIES

1157. FAUST, L. B.: **Low speed wind tunnel test of the 0.036 scale B-1 aero force model 2, volume 1.** (NAAL-637). AD-B043302L NA-71-257-VOL-1 1971. 80X72987 US GOV AGENCIES

1158. STILES, R. L.: **Low speed wind tunnel tests of an 0.036-scale model of the B-1 air vehicle, aero force model 3 (NAAL-636)** AD-B043224L NA-71-53 1971. 80X72986 US GOV AGENCIES

1159. KELLY, R.; SITAR, D.: **Analysis of the low speed aerodynamic characteristics of the .036 scale B-1 force model 2 in the North American Rockwell low speed wind tunnel, NAAL 637.** AD-B043512L NA-71-151 1971. 80X73728 US GOV AGENCIES

1160. STONE, G. M., JR.: **Trisonic wind-tunnel tests of the B-1 hot jet model to investigate the compatibility between airframe and jet engine exhaust at three degrees yaw TWT-244 test 3.** AD-B043094L NA-71-988 1971. 80X73272 US GOV AGENCIES

1161. ANDERSON, K. F.; BEEMAN, R. R.; KARGER, W. J.; SCHLOSSER, D. C.: **Analysis of subsonic aerodynamic characteristics of various 0.04-scale and 0.043-scale B-1 configurations.** AD-B043303L NA-70-396 1970. 80X74120 US GOV AGENCIES

1162. RICHEY, G. K.; BOWERS, D. L.; KOSTIN, L. C.; PRICE, E. A., JR. **Wind Tunnel/Flight Test Correlation Program on the B-1 nacelle afterbody/nozzle at transonic conditions.** AIAA PAPER 78-989 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 8 p. 1978. 78A48469

The B-1 Wind Tunnel/Flight Test Correlation Program had the objective to investigate the B-1 propulsion nacelle flow field differences between wind tunnel and flight test and determine the sources of these differences. The wind tunnel and flight tests of the program are discussed and a description is presented of the corresponding nacelle afterbody/nozzle instrumentation. A 0.06 scale B-1 nozzle afterbody model was used as wind tunnel model. Flight data were obtained during the B-1 No. 2 structural test flight development program. The test results obtained in the investigations provide a good data base for the study of the flow characteristics in transonic flow and differences/similarities between wind tunnel and flight for an exhaust nozzle/aftbody system which is closely integrated with the wing and fuselage.

1163. KISER, C. E.; **Results of the B-1 .07 scale external compression inlet drag model wind tunnel test.**: Rep. NA-74-159, B-1 Div., Rockwell International, Dec. 1974. 78X76901

1164. Airframe engine integration plan B-1 air vehicle F101-GE-100 engine turbofan, augmented. AD-B026474L NA-69-982-1 1971. 78X75930 US GOV AGENCIES

1165. RICHEY, G. K.; PETERSEN, M. W.; PRICE, E. A., JR.: **Wind tunnel/flight test correlation program on the B-1 nacelle afterbody/nozzle.**: AIAA PAPER 76-673 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 12th, Palo Alto, Calif., July 26-29, 1976, AIAA 26 p. 76A42419

Results of wind tunnel tests of an instrumented 0.06-scale B-1 full aircraft configuration jet effects model are discussed with particular reference to the afterbody/nozzle region. The objective was to investigate and improve correlation procedures between wind tunnel and flight test data for the flow fields associated with the inlet and nozzle of an integrated configuration with airframe/propulsion interference effects representative of advanced transonic/supersonic aircraft. With pressure instrumentation on the nacelle afterbody/nozzle, wind tunnel data indicate good correlation between the forces on the nacelle derived from pressure-area integration and direct measurement with a metric afterbody/nozzle balance. Investigated areas include the effect of model configuration, nozzle pressure ratio, Reynolds number, strut effects, faired-over versus flow-through nacelle, and simulation of inlet bypass and spillage flow.

1166. LAUER, R. F., Jr.; **Results of 0.2-scale B-1 production inlet development and verification tests at subsonic and supersonic Mach numbers.**: AEDC-TR-75-57, U.S. Air Force, May 1975. 76X72704

1167. MCDILL, H. E.; **Results of a full-scale B-1 inlet/engine compatibility test at subsonic and supersonic Mach numbers.**: AEDC-TR-75-3, U.S. Air Force, Jan. 1975. 75X75799

1168. HAAGENSON, W. R.; RANDALL, L. M.: **Inlet development for the B-1 strategic bomber.** AIAA PAPER 74-1064 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Propulsion Conference, 10th, San Diego, Calif., Oct. 21-23, 1974, AIAA 9 p. 1974. 75A10258

The B-1 inlet was originally a mixed compression design, but later changed to an external compression inlet (ECI). All major problems encountered in adapting the ECI to the B-1 were solved during the first wind tunnel development test. Aerodynamic characteristics of the inlet and, particularly, the characteristics of certain inlet control parameters are associated with the underwing location of the nacelle. Inlet distortion and inlet/engine compatibility have been carefully audited throughout the B-1 program. A demonstration of inlet/engine compatibility before first flight was provided by wind tunnel tests of a full-scale inlet/engine model at Arnold Engineering Development Center.

1169. BLACK, J. A.; **A wind tunnel test of a 0.07-scale inlet drag model of the B-1 aircraft at Mach numbers from 0.60 to 1.60.**: AEDC-TR-73-188, U.S. Air Force, Nov. 1973. 74X70938

12.8 MISCELLANEOUS AIRCRAFT

1170. SWEETMAN, BILL: **Blackjack - Air defence challenge for the 1990s**. Interavia (ISSN 0020-5168), vol. 43, Oct. 1988, p. 1012-1014. 89A15024

The USSR's 'Blackjack' supersonic cruise-capable bomber is the largest aircraft ever designed for a combat mission, being as much as 50 percent heavier than the U.S. B-1B. The present analysis of its design features, with a view to its intended operational environment, notes the design to emphasize the high speed/altitude corner of the performance envelope, unlike the low-level/subsonic-penetration B-1B. One weapons bay of more than 40-ft length is incorporated ahead of the wing carry-through box; a 25-ft-long bay is located behind it. Both bays can accommodate rotary launchers for six AS-15 cruise missiles; the long forward bay could in addition carry several thermonuclear free-fall bombs. Maximum speed may be in excess of Mach 2 at 60,000 ft.

1171. AUZINS, J.: **Measurement and correlation of structural response to inlet hamershock phenomena on an F-14 airplane**. Society of Flight Test Engineers, Journal, vol. 2, May 1980, p. 27-36. 80A34975

Engine stalls in high speed jet aircraft can result in hammershock and inlet buzz. When these phenomena do occur, they can impose significant air/inertia loads on the inlet structure and external stores. Although hammershock and inlet buzz are part of the design criteria, flight tests are necessary to quantify these effects which result from the complex interaction of propulsive, aerodynamic, geometric and dynamic store response characteristics of the flight vehicle. This paper describes the tests and analytical methodology developed during the F-14A flight test program to assess the structural effects of engine stalls while maintaining the required structural margins.

13.0 OTHER ISSUES

13.1 ENVIRONMENTAL/ECONOMICS

1172. FORESTIER, J.; LECOMTE, P.; POISSON-QUINTON, PH.: **Supersonic air transport programs in the 60's**. IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 14-29. In French. 1990. 91A10952

A review of the SST programs conducted by the United States, France, Great Britain and the USSR during the 1960s is presented. The designs that evolved considered such questions as the supersonic boom and other noise related problems that were directly related to environmental and public opinion issues. Development of the Concorde program is discussed, and a brief outline of the TU 144 project and the discontinued U.S. SST competition is presented. Some aspects of initial Concorde operational problems are also described.

1173. BAHR, DONALD W.: **Supersonic/hypersonic propulsion systems - Exhaust emission characteristics and abatement technology**. IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 167-170. 1990. 91A10965

A study of pollutant emissions of aircraft turbine engines is presented. These pollutants consist primarily of smoke, unburned hydrocarbons and oxides of nitrogen. The HC and CO emissions are principally produced at low thrust levels while smoke and NO(x) result mainly from high thrust operating conditions. Continuing technological development has served to radically reduce smoke, HC, and CO emissions so that, at present, cruise NO(x) emissions are the only significant category remaining. Modeling studies show that the NO(x) cruise operating emissions of SST and HST transport aircraft engines may have possible adverse effects on the stratospheric ozone layer. Therefore, the development of SST engine combustors capable of satisfactory operation with significantly reduced NO(x) levels than those of present technology combustors is necessary.

1174. High Speed Civil Transport Study: Special factors. NASA-CR-181881 NAS 1.26:181881 1990. 90N28537

Studies relating to environmental factors associated with high speed civil transports were conducted. Projected total engine emissions for year 2015 fleets of several subsonic/supersonic transport fleet scenarios, discussion of sonic boom reduction methods, discussion of community noise level requirements, fuels considerations, and air traffic control impact are presented.

1175. Study of high-speed civil transports. Summary. NASA-CR-4236 NAS 1.26:4236 1990. 90N25966

A systems study to identify the economic potential for a high-speed commercial transport has considered technology, market characteristics, airport infrastructure, and environmental issues. Market forecasts indicate a need for high speed civil transport (HSCT) service in the 2000/2010 time frame conditioned on economic viability and environmental acceptability. Design requirements focused on a 300 passenger, 3 class service, and 6500 nautical mile range based on the accelerated growth of the Pacific region. Compatibility with existing airports was an assumed requirement. Mach numbers between 2 and 25 were examined in conjunction with the appropriate propulsion systems, fuels, structural materials, and thermal management systems. Aircraft productivity was a key parameter with aircraft worth, in comparison to aircraft price, being the airline-oriented figure of merit. Aircraft screening led to determination that Mach 3.2 (TSJF) would have superior characteristics to Mach 5.0 (LNG)and the recommendation that the next generation high-speed commercial transport aircraft use a kerosene fuel. The sensitivity of aircraft performance and economics to environmental constraints (e.g., sonic boom, engine emissions, and airport/community noise) was identified together with key technologies. In all, current technology is not adequate to produce viable HSCTs for the world marketplace. Specific technology requirements have been identified which was the prime objective of this study. National economic benefits are projected.

1176. ALLEN, G. E.; CHAMPAGNE, G.; KLEIN, H. L.; ADLER, R. : **Benefits of advanced materials, structures, and aerodynamics in future high speed civil transport propulsion systems.**: AIAA PAPER 90-3285 AIAA, AHS, and ASEE, Aircraft Design, Systems and Operations Conference, Dayton, OH, Sept. 17-19, 1990. 9 p. 1990. 90A48872

Recent studies conducted under the NASA sponsored High Speed Civil Transport (HSCT) program have indicated that a significant market opportunity exists for a 2nd generation supersonic commercial transport by the early 21st century. The aircraft must be economically competitive with a subsonic transport fleet and meet stringent environmental constraints, particularly in relation to community noise and nitrous oxide emissions. The propulsion system represents a critical element in achieving an economically affordable, environmentally acceptable High Speed Civil Transport. This paper identifies key propulsion system material, structural, and aerodynamic technologies required for an integrated HSCT aircraft/propulsion system designed for a 5000 nautical mile Mach 3.2 cruise. The benefits of these key technologies are also presented in terms of aircraft takeoff gross weight, fuel consumption, and cruise NOx emissions.

1177. HABRARD, ALAIN: **The variable-cycle engine - A solution to the economical and environmental challenge of the future supersonic transport.** IN: European Symposium on the Future of High Speed Air Transport, Strasbourg, France, Nov. 6-8, 1989, Proceedings (91A10951 01-01). Toulouse, France, Cepadues-Editions, 1990, p. 211-218. 1990. 91A10969

The optimization of a variable-cycle engine designed for the Mach 2 cruise regime is presented. Principal areas of study include specific fuel consumption; the requirements for noise attenuation on the ground, during takeoff and in cruise; by-pass ratios, the reduction of pollutant emissions; adaptive combustors; and a specific variable-cycle engine concept. A variable-cycle engine would have a cycle different for takeoff and subsonic operation from the supersonic regime. As an example, a double-flow cycle with a bypass ratio of 1 to 2 could be used during takeoff while a single-flow cycle would operate in cruise. The specific variable-cycle engine concept discussed corresponds to a good compromise between engine complexity and air inlet/nozzle complexity. Thus it is possible to achieve necessary installed performance and also meet current noise regulations without resorting to new unproven devices.

1178. DOLLYHIGH, SAMUEL M.: **Technology issues for high-speed civil transports.** SAE PAPER 892201 SAE, Aerospace Technology Conference and Exposition, Anaheim, CA, Sept. 25-28, 1989. 11 p. 1989. 90A45422

Current efforts to prepare the technology for a new generation of high-speed civil transports are focused primarily on environmental issues.This paper reports on studies to provide: (1) acceptable engine emissions;(2) reduced airport/community noise; and (3) sonic-boom minimization. Attention is also given to technologies that allow a lighter, more efficient vehicle and to other high-payoff technologies, such as supersonic laminar flow; these have the potential for yielding not only better mission performance but also enhanced environmental compatibility for these new vehicles. The technology issues are reviewed in terms of the technologies themselves and their impact on the equally crucial need for economic success.

1179. COONS, LEE: **Advanced materials for future high speed civil transport.** In NASA, Lewis Research Center, HITEMP Review 1989: Advanced High Temperature Engine Materials Technology Program. 1989. 90X10098 DOMESTIC

Major aerospace technological undertakings of the past continue to be built upon through planned future initiatives. With the emergence of other nations in the aerospace field, the United States must develop visionary initiatives that are both economically sound and environmentally acceptable if it is to retain its leadership; initiatives that not only bring new capabilities that maintain American leadership, but also provide economic growth for the United States. High payoff materials and structures required to meet the needs of an economically affordable and environmentally acceptable HSCT are being identified. A study aircraft was configured and a baseline engine was defined with current state-of-the-art materials and structures. Major advances in materials, structures, and aerodynamics were then incorporated into an advanced technology engine. A lower risk advanced technology engine was also studied to determine the impact of reducing operating temperatures. There are a number of challenges to be overcome to realize the potential of the HSCT. These challenges cover not only material development but also understanding of structural failure modes, design criteria, and development of affordable manufacturing processes. All of these challenges come with a price. Although the challenge is great, the payoff will allow the United States to maintain leadership in aerospace technology.

1180. Study of high-speed civil transports. NASA-CR-4235 NAS 1.26:4235 1989. 90N13370

A systems study to identify the economic potential for a high-speed commercial transport (HSCT) has considered technology, market characteristics, airport infrastructure, and environmental issues. Market forecasts indicate a need for HSCT service in the 2000/2010 time frame conditioned on economic viability and environmental acceptability. Design requirements focused on a 300 passenger, 3 class service, and 6500 nautical mile range based on the accelerated growth of the Pacific region. Compatibility with existing airports was an assumed requirement. Mach numbers between 2 and 25 were examined in conjunction with the appropriate propulsion systems, fuels, structural materials, and thermal management systems. Aircraft productivity was a key parameter with aircraft worth, in comparison to aircraft price, being the airline-oriented figure of merit. Aircraft screening led to determination that Mach 3.2 (TSJF) would have superior characteristics to Mach 5.0 (LNG) and the recommendation that the next generation high-speed commercial transport aircraft use a kerosene fuel. The sensitivity of aircraft performance and economics to environmental constraints (e.g., sonic boom, engine emissions, and airport/community noise) was identified together with key technologies. In all, current technology is not adequate to produce viable HSCTs for the world marketplace. Technology advancements must be accomplished to meet environmental requirements (these requirements are as yet undetermined for sonic boom and engine emissions). High priority is assigned to aircraft gross weight reduction which benefits both economics and environmental aspects. Specific technology requirements are identified and national economic benefits are projected.

1181. High-speed civil transport study. NASA-CR-4233 NAS 1.26:4233 1989. 89N27648

A system study of the potential for a high-speed commercial transport has addressed technological, economic, and environmental constraints. Market projections indicate a need for fleets of transports with supersonic or greater cruise speeds by the year 2000 to 2005. The associated design requirements called for a vehicle to carry 250 to 300 passengers over a range of 5,000 to 6,000 nautical miles. The study was initially unconstrained in terms of vehicle characteristic, such as cruise speed, propulsion systems, fuels, or structural materials. Analyses led to a focus on the most promising vehicle concepts. These were concepts that used a kerosene-type fuel and cruised at Mach numbers between 2.0 to 3.2. Further systems study identified the impact of environmental constraints (for community noise, sonic boom, and engine emissions) on economic attractiveness and technological needs. Results showed that current technology cannot produce a viable high-speed civil transport; significant advances are required to reduce takeoff gross weight and allow for both economic attractiveness and environmental acceptability. Specific technological requirements were identified to meet these needs.

1182. High-speed civil transport study. Summary. NASA-CR-4234 NAS 1.26:4234 1989. 89N27647

A system of study of the potential for a high speed commercial transport aircraft addressed technology, economic, and environmental constraints. Market projections indicated a need for fleets of transport with supersonic or greater cruise speeds by the years 2000 to 2005. The associated design requirements called for a vehicle to carry 250 to 300 passengers over a range of

5000 to 6000 nautical miles. The study was initially unconstrained in terms of vehicle characteristics, such as cruise speed, propulsion systems, fuels, or structural materials. Analyses led to a focus on the most promising vehicle concepts. These were concepts that used a kerosene type fuel and cruised at Mach numbers between 2.0 to 3.2. Further systems study identified the impact of environmental constraints (for community noise, sonic boom, and engine emissions) on economic attractiveness and technological needs. Results showed that current technology cannot produce a viable high speed civil transport. Significant advances are needed to take off gross weight and allow for both economic attractiveness and environment acceptability. Specific technological requirements were identified to meet these needs.

1183. LOWRIE, B. W.; DENNING, R. M.; GUPTA, P. C.: **The next generation supersonic transport engine: Critical issues.** PNR90576 BLO/163 ETN-89-95556 1989. 90N12605

The design of a successor to the Concorde with a longhaul range of 5500 nautical miles is discussed. The ability of the engine and airframe to produce this range economically is briefly examined. Some offdesign implications of choice of cruise Mach number on matching and subsonic performance are outlined. Environmental requirements which can be controlled or influenced by engine design are discussed and the key issues noted. Consequent requirements for engine cycle variability are defined and two possibilities assessed.

1184. MORRIS, SHELBY J., GEISELHART, KARL A.(Planning Research Corp., Hampton, VA.), COEN, PETER G.; **Performance potential of an advanced technology Mach 3 turbojet engine installed on a conceptual high-speed civil transport.**: NASA-TM-4144; L-16531; NAS 1.15:4144. Nov. 1989, 31 p. 90N10034

The performance of an advanced technology conceptual turbojet optimized for a high-speed civil aircraft is presented. This information represents an estimated performance of a Mach 3 Brayton (gas turbine) cycle engine optimized for minimum fuel burned at supersonic cruise. This conceptual engine had no noise or environmental constraints imposed upon it. The purpose of this data is to define an upper boundary on the propulsion performance for a conceptual commercial Mach 3 transport design. A comparison is presented demonstrating the impact of technology proposed for this conceptual engine on the weight and other characteristics of a proposed high-speed civil transport. This comparison indicates that the advanced technology turbojet described could reduce the gross weight of a hypothetical Mach 3 high-speed civil transport design from about 714,000 pounds to about 545,000 pounds. The aircraft with the baseline engine and the aircraft with the advanced technology engine are described.

1185. MOXON, JULIAN: **Civil supersonics - Propulsion is the key.** Flight International (ISSN 0015-3710), vol. 135, June 10, 1989, p. 116, 117, 119, 122. 89A45031

Of the three most important environmental problems facing next-generation SST designers, including sonic boom overpressures, NOx pollution of the stratosphere, and airport noise, the latter two are directly addressable by propulsion system design efforts. Attention is presently given to the variable-cycle engine (VCE) efforts of three major aircraft propulsion system manufacturers in the U.S. and Britain; their VCE configurations address the aforementioned problems by varying the amount of turbofan-bypass air from a high flow rate at subsonic speeds to a low one in supersonic cruise. Cooler combustion temperatures reduce NOx, and lower exhaust velocities associated with high-bypass subsonic flow reduce takeoff and landing noise-generating exhaust stream velocities.

1186. SMITH, MARTIN G., JR.: **21st century high speed transport propulsion.** AIAA PAPER 88-2987 AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference, 24th, Boston, MA, July 11-13, 1988. 9 p. 88A44718

The NASA-sponsored High Speed Commercial Transport (HSCT) program's marketing studies have given attention to 300-passenger 6000-n. mi. range supersonic transports operating in the Mach 2-5 range. A key factor in the feasibility of such aircraft is the propulsion system chosen, which in addition to being fuel efficient must be reliable and environmentally acceptable. These studies have recently progressed to the point where the speed regime for the HSCT has been narrowed to Mach 2-plus to Mach 3-plus, using a kerosene-type fuel. A subsequent, more advanced vehicle may use liquid natural gas to cruise at speeds of up to Mach 5.

1187. STRACK, WILLIAM C.; MORRIS, SHELBY J., JR.: **The challenges and opportunities of supersonic transport propulsion technology AIAA PAPER 88-2985.** AIAA, ASME, SAE, and ASEE, Joint Propulsion Conference and Exhibit, 24th, Boston, MA,

July 11-13, 1988. 13 p. Previously announced in STAR as 88N23806. 1988. 88A48032

The major challenges confronting the propulsion community for civil supersonic transport applications are identified: high propulsion system efficiency at both supersonic and subsonic cruise conditions, low-cost fuel with adequate thermal stability at high temperatures, low noise cycles and exhaust systems, low emission combustion systems, and low drag installations. Both past progress and future opportunities are discussed in relation to perceived technology shortfalls for an economically successful airplane that satisfies environmental constraints.

1188. JACKSON, CHARLIE M., JR.; MORRIS, CHARLES E. K., JR.: **Unique research challenges for high-speed civil transports.** NASA-TM-100490 NAS 1.15:100490 1987. 87N27651

Market growth and technological advances are expected to lead to a generation of long-range transports that cruise at supersonic or even hypersonic speeds. Current NASA/industry studies will define the market windows in terms of time frame, Mach number, and technology requirements for these aircraft. Initial results indicate that, for the years 2000 to 2020, economically attractive vehicles could have a cruise speed up to Mach 6. The resulting research challenges are unique. They must be met with technologies that will produce commercially successful and environmentally compatible vehicles where none have existed. Several important areas of research were identified for the high-speed civil transports. Among these are sonic boom, takeoff noise, thermal management,lightweight structures with long life, unique propulsion concepts, unconventional fuels, and supersonic laminar flow.

1189. STRACK, WILLIAM C.: **Propulsion challenges and opportunities for high-speed transport aircraft**. In its Aeropropulsion '87. Session 6: High-Speed Propulsion Technology, 19 p (See 88N15807) 1987. 88N15809

For several years there was a growing interest in the subject of efficient sustained supersonic cruise technology applied to a high-speed transport aircraft. The major challenges confronting the propulsion community for supersonic transport (SST) applications are identified. Both past progress and future opportunities are discussed in relation to perceived technology shortfalls for an economically successful SST that satisfies environmental constraints. A very large improvement in propulsion system efficiency is needed both at supersonic and subsonic cruise conditions. Toward that end, several advanced engine concepts are being considered that, together with advanced discipline and component technologies, promise at least 40 percent better efficiency that the Concorde engine. The quest for higher productivity through higher speed is also thwarted by the lack of a conventional, low-priced fuel that is thermally stable at the higher temperatures associated with faster flight. Airport noise remains a tough challenge because previously researched concepts fall short of achieving FAR 36 Stage 3 noise levels. Innovative solutions may be necessary to reach acceptably low noise. While the technical challenges are indeed formidable, it is reasonable to assume that the current shortfalls in fuel economy and noise can be overcome through an aggressive propulsion research program.

1190. DRIVER, C.; MAGLIERI, D. J.: **The impact of emerging technologies on an advanced supersonic transport**. ICAS, Congress, 15th, London, England, September 7-12, 1986, Proceedings. Volume 1 (86A48976 24-01). New York, American Institute of Aeronautics and Astronautics, Inc., 1986, p. 213-220. 86A48997

The effects of advances in propulsion systems, structure and materials, aerodynamics, and systems on the design and development of supersonic transport aircraft are analyzed. Efficient propulsion systems with variable-cycle engines provide the basis for improved propulsion systems; the propulsion efficiencies of supersonic and subsonic engines are compared. Material advances consist of long-life damage-tolerant structures, advanced material development, aeroelastic tailoring, and low-cost fabrication. Improvements in the areas of aerodynamics and systems are examined. The environmental problems caused by engine emissions, airport noise, and sonic boom are studied. The characteristics of the aircraft designed to include these technical advances are described.

1191. DRIVER, C.: **Progress in supersonic cruise technology**. NATO, AGARD, Symposium/Workshop on Sustained Supersonic Cruise and Maneuver, Brussels, Belgium, Oct. 10-13, 1983, Paper. 11 p. 83A43025

The Supersonic Cruise Research (SCR) program identified significant improvements in the technology areas of aerodynamics, structures, propulsion, noise reduction, takeoff and landing procedures, and advanced configuration concepts. These improvements, when combined in a large supersonic cruise vehicle, offer a far greater technology advance than generally realized. They offer the promise of an advanced commercial family of

aircraft which are environmentally acceptable, have flexible range-payload capability, and are economically viable. These same areas of technology have direct application to smaller advanced military aircraft and to supersonic executive aircraft. Several possible applications will be addressed.

1192. FISHBACH, L. H.; STITT, L. E.; STONE, J. R.; WHITLOW, J. B., JR.: **NASA research in supersonic propulsion: A decade of progress.** NASA-TM-82862 NAS 1.15:82862 1982. 82N26300

A second generation, economically viable, and environmentally acceptable supersonic aircraft is reviewed. Engine selection, testbed experiments, and noise reduction research are described.

1193. ALLAN, R. D.; HINES, B. G.; WINES, W. L.: **Effect of design temperature on double bypass engines for SCR.** NASA-CR-167854NAS 1.26:167854 R82AEB225 1982. 82X10342 US GOV AGENCIES AND CONTRACTORS

NASA is engaged in a study of the application of advanced technology to long range, supersonic, commercial transport aircraft under the Supersonic Cruise Research (SCR) Program. As part of this study, General Electric has defined and refined variable cycle engine (VCE) concepts that meet the performance and environmental requirements for an advanced, supersonic cruise vehicle. Studies have shown that the double bypass VCE with an oversize front block fan and outer stream mechanical suppressors can meet low noise goals. The technology utilized for most of these engines is considered advanced technology which will be available to start engine development programs in the late 1980's. Component efficiencies, materials, turbine temperatures, and cooling techniques are all effected by the selected technology levels. This current study effort (NASA Contract NAS3-22749) examines the effect of varying the turbine inlet temperature of the cycle from 1427 to 1649 C (2600 to 3000 F) and shows the effect of these temperature levels, as measured by airplane takeoff gross weight to fly a 7408 km (4000 nmi) mission), and by engine operating and acquisition cost. At each temperature level, a parametric cycle study was performed to select the best bypass ratio, fan pressure ratio, and overall pressure ratio.

1194. ROWE, W. T.: **Technology development status at McDonnell Douglas.** In NASA, Langley Research Center Supersonic Cruise Research, 1979, Pt. 2, p 873-888 (See 81N18005 09-01) 1981. 81N18019

The significant technology items of the Concorde and the conceptual MCD baseline advanced supersonic transport are compared. The four major improvements are in the areas of range performance, structures (materials), aerodynamics, and in community noise. Presentation charts show aerodynamic efficiency; the reoptimized wing; low scale lift/drag ratio; control systems; structural modeling and analysis; weight and cost comparisons for super- plasticity diffusion bonded titanium sandwich structures and for aluminum brazed titanium honeycomb structures; operating cost reduction; suppressor nozzles; noise reduction and range; the bicone inlet; a market summary; environmental issues; high priority items; the titanium wing and fuselage test components; and technology validation.

1195. ROWE, W. T.; WELGE, H. R.; JOHNSON, E. S.; ROCHTE, L. S.: **Advanced supersonic transport propulsion and configuration technology improvements.** AIAA PAPER 81-1595 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 13 p. 81A40970

This paper presents the results of recent Douglas Aircraft Company integration studies for an advanced supersonic transport. The studies include technology improvements such as superplastic formed and diffusion-bonded titanium sandwich primary structure, composite secondary structure, bicone engine inlet, improved mechanical suppressors based on flight test data, improved aerodynamic efficiency based on wind tunnel test data, and updated performance for both variable-cycle and low-bypass-ratio engines. Technology development requirements for an economically viable and environmentally acceptable advanced supersonic transport are defined through these studies. A new Douglas Aircraft Company baseline supersonic transport designed to carry 350 passengers is defined for cost comparisons.

1196. WESTMORELAND, J. S.; PACKMAN, A. B.: **A successful step toward an advanced supersonic transport engine - Acoustic and emission results from the Pratt and Whitney Aircraft Variable Cycle Engine Program.** AIAA PAPER 81-1593 AIAA, SAE, and ASME, Joint Propulsion Conference, 17th, Colorado Springs, CO, July 27-29, 1981, AIAA 10 p. 81A40968

Test results of the successful NASA acoustic evaluation of the supersonic transport Variable Stream Control Engine (VSCE) are presented. The engine, simulated by the attachment of a three-stage combustor duct burning system with coannular nozzles to a testbed F100 turbofan engine, was found to be environmentally and operationally feasible; with burner emissions being extremely low and duct burner noise not being evident in the far field. Among the topics covered are: (1) VSCE and testbed engine configurations; (2) duct burner configuration and emissions/performance evaluation; (3) system performance goals at sea-level takeoff and supersonic cruise conditions; (4) VSCE acoustic goals and test results, including aft fan component and jet exhaust noise; and (5) estimates of flyover noise.

1197. SIGALLA, A.: **Overview of Boeing supersonic transport efforts, 1971 - 1979**. In NASA, Langley Research Center Supersonic Cruise Research, 1979, Pt. 2, p 821-832 (See 81N18005) 1980. 81N18016

Following cancellation of the United States Supersonic Transport program, the status of the technology was assessed carefully and emphasis was put on finding solutions for what were considered the major technical difficulties. In particular, work on the breakthroughs needed to advance the technology was emphasized. Currently, solutions to all major technical problems are identified. Depending on the subject, either the problem is no longer a concern or the steps needed to bring about a solution are mapped out clearly. Throughout the NASA SCR program, important strides were made in the identification of design advances which would greatly improve supersonic airplane fuel efficiency, noise, and other performance and cost affecting parameters. Furthermore, these efforts created an atmosphere in which it was possible for new ideas to flourish and positive inventions to take place such as the variable cycle engine and the blended fuselage. These technical gains show that, given availability of such technology, advanced supersonic transports could be developed that would be economically successful and environmentally acceptable.

1198. Advanced concept studies for supersonic vehicles. NASA-CR-159244 D6-48864 1980. 80X10116 US GOV AGENCIES AND CONTRACTORS

The characteristics and research requirements are defined for future supersonic cruise aircraft that would offer superior performance, reduced fuel consumption, and less noise and environmental impact, as well as economical acquisition and operational cost. Many technical advances important to the design of supersonic cruise aircraft are reported, and it is shown that their integration into practical airplane design concepts is feasible.

1199. KOZLIN, J. R.: **F100 exhaust nozzle area control.** In NASA Langley Research Center Proc. of the 14th Aerospace Mech. Symp., p 211-223 (See 80N23495 14-31) 1980. 80N23513

The details of the F100 nozzle mechanism design are highlighted, placing particular emphasis upon the evolution of design constraints or drivers from initial concept through current operational deployment. A kinematic description of the area control mechanism is given, and several environmental constraints which complicate the normal mechanism design process are discussed.

1200. WILSON, J. R.; BENSON, J. L.: **Propulsion system airframe integration studies - Advanced supersonic transport.** AIAA PAPER 78-1053 American Institute of Aeronautics and Astronautics and Society of Automotive Engineers, Joint Propulsion Conference, 14th, Las Vegas, Nev., July 25-27, 1978, AIAA 7 p. 1978. 78A48488

One of the objectives of the considered integration studies is related to the identification of engine/airframe configurations which offer the best performance potential within environmental constraints. Other objectives include the identification of engine cycle and geometry improvements, the development of practical preliminary designs of most promising configurations, and the identification of test and development program requirements. The variables examined in the study are related to the engine nacelle location, the inlet configuration, the engine cycle/configuration, engine-inlet airflow match, engine thrust schedule, and engine accessory location. Attention is given to propulsion system configurations, tradeoff studies, engine-inlet matching studies, aspects of nacelle design integration, and engine operational procedures.

13.2 MISCELLANEOUS

1201. ALLEN, G. E.; CHAMPAGNE, G.; KLEIN, H. L.; ADLER, R. : **Benefits of advanced materials, structures, and aerodynamics in future high speed civil transport propulsion systems.**: AIAA PAPER 90-3285 AIAA, AHS, and ASEE, Aircraft Design, Systems and

Operations Conference, Dayton, OH, Sept. 17-19, 1990. 9 p. 1990. 90A48872

Recent studies conducted under the NASA sponsored High Speed Civil Transport (HSCT) program have indicated that a significant market opportunity exists for a 2nd generation supersonic commercial transport by the early 21st century. The aircraft must be economically competitive with a subsonic transport fleet and meet stringent environmental constraints, particularly in relation to community noise and nitrous oxide emissions. The propulsion system represents a critical element in achieving an economically affordable, environmentally acceptable High Speed Civil Transport. This paper identifies key propulsion system material, structural, and aerodynamic technologies required for an integrated HSCT aircraft/propulsion system designed for a 5000 nautical mile Mach 3.2 cruise. The benefits of these key technologies are also presented in terms of aircraft takeoff gross weight, fuel consumption, and cruise NOx emissions.

1202. BECKER, DOROTHY L.: **Fuels for Future High-Speed Flight Vehicles. Volume 1: JANNAF Ramjet Subcommittee Workshop.**: CPIA-PUBL-518-VOL-1 AD-B141616L 1988. 90X72488 DOMESTIC

1203. LEE, C. M.: **Thermally stable liquid fuels for high speed civil transport.** In JHU, Fuels for Future High -Speed Flight Vehicles, Volume 1: JANNAF Ramjet Subcommittee Workshop, p 61-86 (See 90X72488 16-2) 1988. 90X72490 DOMESTIC

1204. CENKO, A.; TINOCO, E. N.; DYER, R. D.; DEJONGH, J. **PAN AIR applications to weapons, carriage and separation.** AIAA PAPER 80-0187 American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 18th, Pasadena, Calif., Jan. 14-16, 1980, 11 p. 1980. 80A23939

The paper deals with the PAN AIR technology for analyzing the complex flow phenomena associated with aircraft/weapons carriage and mutual interference during separation. Both subsonic and supersonic cases are considered. Force, moment, and flow field characteristics are compared against experimental results for a fighter aircraft and a tangent ogive store.

1205. CAWTHORN, JACK A.; TRUAX, PHILIP P.; SAVAGE, TOM M.: **Advanced inlet study (Tailor-Mate II).**: AFFDL-TR-73-72, U. S. Air Force, June 1973. 74X72260

1206. EHERNBERGER, L. J.: **High altitude turbulence for supersonic cruise vehicles.**: NASA-TM-88285 H-1399 AAS-86-418 NAS 1.15:88285. 1987 87N23100

The characteristics of high altitude turbulence and its associated meteorological features are reviewed. Findings based on data from NASA flight research programs with prototype military aircraft, the XB-70 and YF-12A, are emphasized. An example of detailed numerical atmospheric simulations, which may provide greatly increased understanding of these earlier turbulence observations, is presented. Comparisons between observation and numerical simulation should help to delineate the limitations of analysis techniques and improve our understanding of atmospheric processes in the stratosphere.

1207. EHERNBERGER, L. J.: **High altitude turbulence for supersonic cruise vehicles.**: AAS PAPER 86-418; Aerospace century XXI: Space sciences, applications, and commercial developments; Proceedings of the Thirty-third Annual AAS International Conference, Boulder, CO, Oct. 26-29, 1986 (88A35123 13-12). San Diego, CA, Univelt, Inc., 1987, p. 1391-1405. Previously announced in STAR as 87N23100. 1987. 88A35140

The characteristics of high altitude turbulence and its associated meteorological features are reviewed. Findings based on data from NASA flight research programs with prototype military aircraft, the XB-70 and YF-12A, are emphasized. An example of detailed numerical atmospheric simulations, which may provide greatly increased understanding of these earlier turbulence observations, is presented. Comparisons between observation and numerical simulation should help to delineate the limitations of analysis techniques and improve our understanding of atmospheric processes in the stratosphere.

1208. BARTON, J. M.: **The role of computational fluid dynamics in aeropropulsion ground testing.** (American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 21st, Reno, NV, Jan. 10-13, 1983, AIAA Paper 83-0149) Journal of Aircraft (ISSN 0021-8669), vol. 21, Oct. 1984, p. 745-750. Previously

cited in issue 05, p. 599, Accession no.83A16557. 84A49084

1209. RABOUTET, J.: **Supersonic aerial transport: Medical and physiological aspects**. In AGARD Recent Advan. in Aeron. and Space Med., 7 p (See 80N14678 05-51) 1979. 80N14683

From 1964 to 1974, two medical subgroups, one French and one British, researched the medical and physiological problems presented by supersonic air transportation. All the problems were addressed by committees of specialists that included physicians, physicists, chemists, and engineers. Thus, the loss of pressurization, ozone, ionizing radiation, noise, visual problems, and air conditioning were the objects of profound study. Very satisfying solutions were found. In certain cases, notably ozone and cosmic radiation, it could be proved that it was a matter of false problems, and that supersonic flight at 17,000 meters offered no danger.

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APPENDIX A: LITERATURE SEARCH

Description:

The literature search used to generate this bibliography was conducted on the NASA/RECON informational retrieval system for technical publications, operated by the NASA Scientific and Technical Information Facility (STIF). Identified citations were downloaded to a PC for processing. The appropriate references were selected, grouped by subject, and sorted by date. Documents from 1980 to early 1991 are included. For a complete coverage of the subject area, publications of notable reference value prior to 1980 have also been included. Limited distribution documents with access levels of 'domestic NASA' and lower are also listed.

Two separate series of searches were conducted: The first was a strategic search, in which a complicated logical selection of subject term criterea were used to identify the appropriate references since 1980. It was designed to be wide enough in scope to capture all relevant references, without including too many irrelevant ones. The RECON database 'subject terms' used in the search are not entirely consistent, and may vary from one citation to another. Therefore it was necessary to make the search very general, and manually delete the unwanted documents.

The second was a manual search, in which documents of particular merit or reference value were individually retrieved, regardless of their time frame. These were identified by referring to other bibliographies, checking the reference lists of other papers, and consulting experts in the various fields.

RECON database:

The RECON database contains over 2 million citations on a variety of subjects and sources in a number of different file collections, including the complete International Aerospace Abstracts (IAA) and Scientific and Technical Aerospace Reports (STAR) listings. Major subjects include aeronautics, geosciences, astronautics, computer sciences, physics, chemistry/materials, and engineering. Reports from DOD & contractors, NASA & contractors, foreign references, and others sources are listed.

The following file collections were used in the search. The accession number of a reference (for example, 89A12345) indicates which accession series or file collection it belongs to (A-10000 in this case).

A-10000. International Aerospace Abstracts (IAA). Includes periodicals, books, meeting papers, conference proceedings, journal articles, and translations of foreign journal articles.

M-10000. Computer Program Abstracts (CPA). Current year listing of computer programs developed by NASA, DoD, contractors, and other agencies.

N-10000. Scientific and Technical Aerospace Reports (STAR). Includes NASA / NASA contractor / NASA grantee reports; reports by government agengices, domestic and foreign institutions, universities and private firms; translations in report form; NASA patents and applications; dissertations and thesis.

X-10000. Limited Scientific and Technical Aerospace Reports (LSTAR). Contains NASA funded security-classified and limited distribution documents. The database itself contains no classified information.

X-70000. Older Classified Scientific and Technical Aerospace Reports Extended (OCSTARE). Older security classified and limited distribution documents.

The information in the RECON database was processed and formatted into a standard bibliographical entry and abstract; not all of the fields in the database record are shown in the bibliography. Note that the accession number may appear in a format like A89-12345, which is equivalent to 89A12345. The number 89 indicates the year of cataloguing. A sample RECON database entry and a sample bibliography entry are shown in Figures A1 and A2.

Strategic search:

For reference, the complete algorithm of the strategic search is presented here:

For inlets and inlet/airframe configurations, references with subject terms from group 1 AND group 2 were selected:

group 1
- supersonic inlets
- supersonic flow
- internal compression inlets

group 2
- inlet airframe cofigurations
- engine inlets
- inlet flow
- air intakes

For nozzles, nozzle/airframe configurations, and noise, references with subject terms from group 1 AND group 2 were selected:

group 1
- supersonic nozzles
- convergent-divergent nozzles

group 2
- exhaust nozzles
- ejectors
- jet aircraft noise
- nozzle design
- nozzle efficiency
- plug nozzle
- coaxial nozzles

Arrangement and Format of Citations

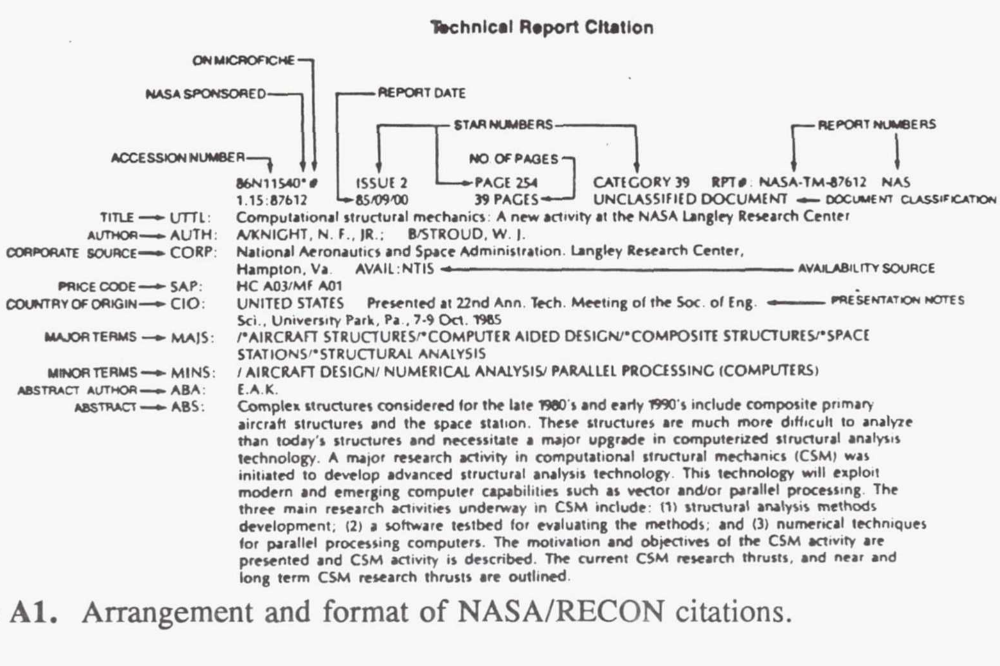

Figure A1. Arrangement and format of NASA/RECON citations.

shrouded nozzles
spike nozzles

For general surveys, conceptual designs and actual aircraft, references with subject terms from group 1 AND group 2 were selected:

group 1
- supersonic cruise aircraft research
- supersonic commercial air transport
- supersonic transports
- concorde aircraft
- Tu-144 aircraft
- Boeing 2707 aircraft
- B-58 aircraft
- B-70 aircraft
- YF-12 aircraft
- B-1 aircraft

group 2
- engine airframe integration
- supersonic flow
- aerodynamic configurations
- wing nacelle configurations
- nozzle geometry
- nozzle flow
- inlet flow
- engine inlets
- aircraft engines
- jet engines
- noise reduction
- jet aircraft noise
- aerodynamic characteristics
- aerodynamics
- flight tests
- wind tunnel tests
- computational fluid dynamics

For engines, references with subject terms in group 1, OR in group 2 AND group 3 were included.

group 1
- variable cycle engines
- variable stream control engines

AUTHORS

REFERENCE NUMBER → **123.** KNIGHT, N. F., JR.; STROUD, W. J.: **Computational structural mechanics: A new activity at the NASA Langley Research Center.** NASA-TM-87612 NAS1.15:87612 1985. ← TITLE, REPORT DATE, REPORT NUMBERS

ACCESSION NUMBER → 86N11540

ABSTRACT → Complex structures considered for the late 1980's and early 1990's include composite primary aircraft structures and the space station. These structures are much more difficult to analyze than today's structures and necessitate a major upgrade in computerized structural analysis technology. A major research activity in computational structural mechanics (CSM) was initiated to develop advanced structural analysis technology. This technology will exploit modern and emerging computer capabilities such as vector and/or parallel processing. The three main research activities underway in CSM include: (1) structural analysis methods development; (2) a software testbed for evaluating the methods; and (3) numerical techniques for parallel processing computers. The motivation and objectives of the CSM activity are presented and CSM activity is described. The current CSM research thrusts, and near and long term CSM research thrusts are outlined.

Figure A2. Typical HSCT PAI bibliography citation and abstract.

group 2
- supersonic cruise aircraft
- supersonic transports

group 3
- aircraft engines
- jet engines

For overall configurations and engine airframe integration, references withsubject terms in group 1 AND group 2 were included

group 1
- supersonic transports
- supersonic cruise aircraft
- supersonic flow
- supersonic aircraft
- transport aircraft
- commercial aircraft

group 2
- nacelles
- wing nacelle confiugurations
- engine airframe integration
- interference lift
- interference drag

Obtaining documents:

Many publications, such as AIAA papers, NASA reports and journal articles, can be obtained easily from conventional sources such as university libraries or research center document collections.

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Other sources for documents are listed in the appendix section of each STAR catalog.

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AUTHOR INDEX

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SUBJECT INDEX

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BIBLIOGRAPHIES

COMPUTATIONAL FLUID DYNAMICS

COMBUSTORS

COMPANY REFERENCES

COMPOSITES/STRUCTURES/MATERIALS

CONFIGURATION DESIGN

CRUISE RANGE

DISTORTION EFFECTS AND FLOW CHARACTERISTICS

EMISSIONS/ENVIRONMENT/ECONOMIC

FEDERAL REGULATIONS

FLIGHT SPEEDS

FOREIGN REFERENCES

INLETS

INTEGRATION/INSTALLATION

JOURNALS/CONFERENCES/MEETINGS

MAJOR SUPERSONIC TRANSPORT EFFORTS

NACELLES

NASA AND OTHER GOVERNMENT REFERENCES

NOISE

NOZZLES

NUMBER OF PASSENGERS

PROPULSION SYSTEMS

REPORTS BY ORGANIZATION

RESTRICTED DOCUMENTS

SONIC BOOM

SYSTEM/MISSION PERFORMANCE

TAKE OFF AND LANDING

TECHNOLOGY ISSUES

TESTS AND TESTING

SELECTED REPORT NUMBER INDEX

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13. ABSTRACT *(Maximum 200 words)*

NASA has initiated the High Speed Research (HSR) program, with the goal to develop technologies for a new generation, economically viable, environmentally acceptable supersonic transport (SST), called the High Speed Civil Transport (HSCT).A significant part of this effort is expected to be in multidisciplinary systems integration, such as in propulsion-airframe integration (PAI). In order to assimilate the knowledge database on PAI for SST type aircraft, a bibliography on this subject has been compiled, with over 1200 entries, full abstracts, and indexes. Related topics are also covered, such as: engine inlets, engine cycles, nozzles, existing supersonic cruise aircraft, noise issues, computational fluid dynamics, aerodynamics, and external interference. All identified documents from 1980 through early 1991 are included; this covers the latter part of the NASA Supersonic Cruise Research (SCR) program, and the beginnings of the HSR program. In addition, some pre-1980 documents of significant merit or reference value are also included. The references were retrieved via a computerized literature search using the NASA RECON database system.

14. SUBJECT TERMS

Engine airframe integration; Supersonic transports; Bibliographies

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